SOME FACTORS CONTROLLING TEAK (*Tectona grandis* L.f.) SEEDLINGS DEVELOPMENT AND PROVENANCE VARIATION WITH PARTICULAR REFERENCE TO THAILAND.

BY

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STATEMENT OF ORIGINALITY

Except where specific acknowledgement is given, this thesis is my own original work.

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ABBREVIATIONS

The following abbreviations have been used throughout this thesis.

A	=	Leaf area
asl	=	Above sea level
Alt	=	Altitude
BA	=	Basal area
^{o}C	=	Degree celsius
CF	=	constant fertility
cm	=	centimetre
CR	=	Provenance Chiengrai, Thailand
cu cm	=	Cubic centimetre
cu m	=	Cubic metre
dm	=	decimetre
fc	=	foot-candle
FD	=	Fertility declining
gm	=	gram
GNP	=	Gross national product
h	=	hour
ha	=	hectare
IRGA	=	Infra-red gas analyser
K	=	Provenance Sungum, Kerala, India
km	=	Kilometre
l	=	Litre
L	=	Leaf length
LAR	=	Leaf area ratio
Lat	=	Latitude
ln	=	Natural logarithm

Long	=	Longitude
m	=	Metre
mb	=	Millibar
mm	=	Millimetre
MMD	=	Moderate mortality decline
M of E	=	Modulus of elasticity
mg	=	Milligram
mt	=	Metric ton
MV	=	Provenance Masale Valley, India
NAR	=	Net assimilation rate
ppm	=	Parts per million
r	=	Correlation coefficient
RMD	=	Rapid mortality decline
S	=	Teak Improvement Centre seed lot number
SK	=	Provenance Sukhothai, Thailand
SO	=	Provenance Mae Gah Seed Orchard, Thailand
sq in	=	Square inch
sq km	=	Square kilometre
TK	=	Provenance Tak, Thailand
W	=	Total dry weight

ABSTRACT

The role of teak (Tectona grandis L.f.) in the Thai economy may decline in the near future due to a reduction of the country's natural teak resource. To maintain the teak resource establishment of teak plantations in Thailand has recently been given high priority.

In this thesis the importance of teak in Thailand is detailed along with the consequent importance of the plantation and tree breeding programmes. As the breeding programme has only been operating since 1965 provenance research is presently of high priority. The thesis reviews provenance variation in teak and records the results from a series of controlled environments studies ~~with~~ examined provenance variation with respect to several controlling environmental factors. which

Reports of variation in natural stand and in provenance trials are reviewed in Chapter 2. Provenance variation exists in many characters with no clear patterns defined to date.

In the experimental studies comparisons were made of provenance performance under differing conditions of temperature and daylength. Provenance comparisons were made:

(a) within Thailand,

and (b) between Thailand and India.

For the within Thailand studies up to five provenances were used and for the Thai-Indian studies up to two provenances from each country.

The studies used young teak seedlings. They commenced between 30 and 49 days after seedling germination and ran for between 53 to 91 days. The studies examined:

(a) The effect of night temperature on growth of five provenances (referred to in the thesis as experiment 3).

(b) The effects of night temperature and daylength on growth of two Thai provenances (experiment 4).

(c) The effect of temperature (day/night) on growth of two Thai and two Indian provenances (experiment 5).

(d) Effect of temperature which approximately corresponded to seasonal temperature of Northern Thailand on growth of one Thai and two Indian provenances (experiment 6).

(e) Effect of temperature on net photosynthetic and dark respiration rates of two Thai and two Indian provenances.

Measurements or calculations of the following were made for each seedling:

(a) Overall growth (height growth, diameter growth and dry matter production) (all experiments).

(b) Growth analysis parameters (relative growth rate, net assimilation rate and leaf area ratio) (experiments 4 and 6).

(c) Distribution of photosynthate (relative root growth, relative stem growth, relative leaf growth and relative growth of shoot and root) (experiments 4, 5 and 6).

(d) Leaf characteristics (leaf area, leaf dimensions of particular leaves (all experiments) and leaf growth of particular leaves) (experiment 5)).

(e) Net photosynthetic and respiration rates (experiment 5).

Growth of teak seedlings was controlled strongly by night temperature but less by daylength. Under controlled environments, the optimum temperature for growth of teak seedlings lay within the ranges 25 to 28°C for night temperature and 30 to 33°C for day temperature. Dry matter production was closely related to leaf area production rather than net assimilation rate. The importance of leaf growth studies was discussed.

Provenance variation exists within Thailand with no clear evidence of regional differences. Intensive evaluation of seed sources within Thailand is strongly recommended. Indian provenances were generally inferior to Thai provenances. Similar studies have shown Indian provenances to be inferior to other sources (e.g. Burma, Laos and Java). There is therefore, a need to continue testing exotic sources in Thailand.

There was evidence of provenance x site interaction. This emphasises the need for detailed provenance trials at all major plantation centres and site types.

INTRODUCTION

Teak (Tectona grandis L.f.) forests are a major natural resource of Thailand which have been utilized for many years. This resource has now been reduced for various reasons including land use pressures to a level which requires urgent plantation establishment to maintain the resource. To ensure as high plantation productivity as possible a tree breeding programme for teak in Thailand was established in early 1965 (Keiding, 1966).

Initial tree breeding work must necessarily include provenance studies to determine the most suitable seed sources and particularly the likelihood of provenance x site interaction. However, field provenance studies are necessarily long-term and the controlled environment studies reported in this thesis were established to give some possible early indications of provenance variation in terms of the environmental factors controlling teak seedling development. Provenance x site interaction is also examined briefly.

The thesis initially outlines the place of teak in the economy of Thailand and the need for the plantation establishment of the species. An outline follows of variation in natural stands of teak and in provenance trials. Finally, the effects of temperature and daylength on growth and provenance differences within Thailand and also between some Thai and Indian provenances are examined under controlled environment conditions.

CHAPTER 1

The Importance of Teak (*Tectona grandis* L.f.) in the Economy of Thailand

1.1 Introduction

Thailand has approximately 92,000 sq. km. of natural teak (*Tectona grandis* L.f) forest (Corvanich, 1968) and is one of the four major teak producing countries of the world, the others being Burma, India and Indonesia (Samaputti, 1973). This chapter outlines the importance of teak in the economy of Thailand and shows the need for a plantation and a plantation research programme with the species.

Initially, the geography, people and economy of Thailand are described in general terms. An outline follows of the historical development and trends in the utilization of the teak resource. Finally the contribution of teak planting programmes to the teak resource is discussed.

1.2 The Geography and People

This section includes general descriptions of the geography and population of Thailand.

1.2.1 Geographic Situation

1.2.1.1 Location and Area

Thailand forms part of the land mass of Southeast Asia situated between latitude 5^{o} to 20^{o} N and longitude 97^{o} to 106^{o} E (Fig 1.1). The country is bordered to the north by Laos and Burma and to the west by lower Burma and the Bay of Bengal. To the east of the country lie Cambodia and Laos, with Thailand and Laos separated by the Mekong River. Southwards lies the Gulf of Thailand. There is a southern peninsular between the

China Sea and the Gulf of Thailand and bounded on the extreme south by Malaysia.

The area of Thailand is approximately 514,000 sq. km (63 million ha) (Komkris, 1965). The length of Thailand from north to south is approximately 1,632 km; the widest part of the country from east to west is approximately 588 km. The coast line amounts to approximately 2,080 km (Kanchananaga, 1941).

1.2.1.2 Topography and Drainage

Topographically, Thailand is divided into five major zones as follows:

(1) The North or West Highlands;

(2) The Central or Chao Phya Plain;

(3) The Northeast or Korat Plateau;

(4) The East or Chantaburi Region; and

(5) The South or Peninsular Region.

(1) The North region is mostly mountainous and contains the catchment areas of four major rivers, namely Ping, Wang Yom and Nan Rivers (Figure 1.1). These rivers combine together to form the Chao Phya River, the most important river of the country, supplying the irrigated water for the main agricultural land of the country - the Central region. The region is heavily forested and contains the most important natural teak forest.

(2) The Central region is the area in close proximity to the Chao Phya River. This is one of the major rice producing and exporting areas of the world. Some forest land, containing mostly deciduous forest, occurs in the westerly part and teak forest occurs sparsely along the border with Burma.

(3) The Northeast region is bounded by the Mekong River in the north and east. This area is the driest zone and over

40% of the total area is farmland, centred on the river valleys of the She and Moon Rivers (Silcock,1967) (Figure 1.1). The remainder of the region is undulating and covered with dry dipterocarp forests, which supply some important timbers, e.g. Teng (Shorea obtusa Wall) and Rang (Pentacme suavis A. DC).

(4) The East region is mountainous, surrounded by the Gulf of Thailand to the south and China Sea to the east. The region is the centre of the upland cash crop industries. However, the surrounding hills carry tropical rain forest which supplies constructional timber for local uses.

(5) The South, the peninsula, has an equatorial climate. Rubber, mining and fishing industries are concentrated in this region. The coastal areas are agricultural, and dense tropical rain forest covers the central mountainous areas down to the southern boundary with Malaysia. Within these forests, Yang (Dipterocarpus spp.) is the most important commercial species. Yang is a very cheap timber for extensive domestic use and ranks second to teak in export value.

1.2.1.3 Climate

The climate is generally warm tropical with high humidity prevailing over the country throughout the year (Chankoa et al.,1972). There is little variation in temperature in the South but rather more variation in the North, whilst rainfall is determined largely by the local monsoon winds:

(i) The southwest monsoon originating from the Indian Ocean determines the wet season, usually from June to October.

(ii) The northeast monsoon from China (sometimes called Siberian Anticyclone) controls the dry season (November-May).

Temperature data are given in Table 1.1. The data presented are for five major capitals, each of which is considered representative of the zone in which it is situated. The zonal differences in temperature variation over the year are shown. In the South mean monthly maxima range from 33°C (April) to 29°C (December) whilst in the North the equivalent range is 36°C (April) to 28°C (December). Similarly the mean monthly minima range from 22°C (February) to 25°C (December) in the South and from 23°C (June) to 13°C (January) in the North.

However, the pattern is modified during the rainy season (June-October). Over this period there are only very slight temperature differences throughout the country with figures for all zones being similar.

Zonal rainfall figures are given in Table 1.2. In all zones there is a wet season (June-October) and a dry season (March-May), but rainfall figures vary appreciably from zone to zone. The higher rainfall occurs in the East and South (2,433 and 2,125 mm respectively) whilst the Northeast, Central and North regions have much lower rainfall (1,440, 1,369 and 1,282 mm respectively). Rainfall distribution in the South also tends to be spread over the whole year which is not the case elsewhere.

1.3 Population

1.3.1 Size and Occupation

The population in 1970 was approximately 36 millions and estimated to be increasing by 3% annually (Silcock, 1967; Anon, 1973). Because of a high birth rate, the country is likely to have a population of approximately 50 million by 1980 (Table 1.3).

Figure 1.1 - Map showing natural teak-bearing zone in Thailand.
Source: Mahaphol (1954)

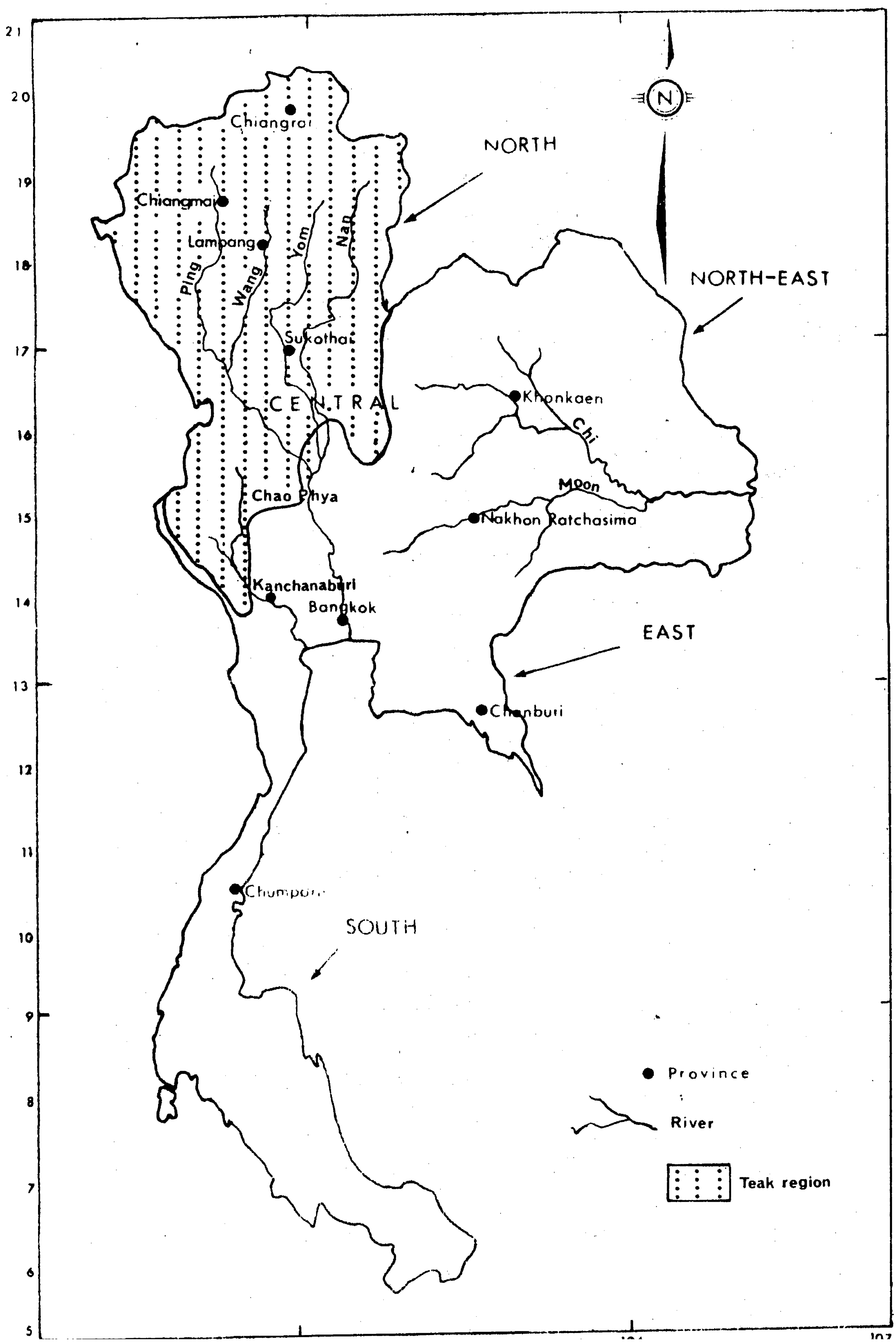


Table 1.1 - Temperature (^{o}C) data for five provincial capitals of Thailand regarded as representative of the five geographical zones of the country.

Provincial Capital	Zone	February			April			June			August			October			December		
		* 1	** 2	*** 3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Chiengmai	North	23.1	32.0	14.0	28.8	36.5	21.0	27.8	32.1	23.5	27.0	30.8	23.2	26.1	30.6	21.6	21.5	28.5	14.5
Bangkok	Central	27.6	32.7	22.4	30.2	35.0	25.5	28.8	32.8	24.9	28.2	32.0	24.3	27.7	31.2	24.2	25.7	31.0	20.4
Khon Kaen	Northeast	25.7	32.9	18.5	30.3	36.9	24.0	28.8	33.1	24.5	28.1	32.2	24.0	26.6	31.5	22.2	22.8	30.1	15.6
Chantaburi	East	26.9	32.9	20.8	28.4	33.7	23.2	27.6	31.1	24.2	27.2	30.6	23.8	27.1	31.2	22.8	25.4	31.3	19.6
Songkhla	South	27.1	30.1	22.4	28.4	32.6	24.1	28.4	32.8	23.9	28.1	32.6	23.6	27.3	31.1	23.5	26.5	29.2	24.8

* 1 = Mean

** 2 = Mean maximum

*** 3 = Mean minimum

Source: Anon (1969)

Table 1.2 - Representative rainfall[1/] data for the five geographical zones of Thailand. Each monthly figure is an average for several stations within the zone.

Zones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Duration* (days)
North	5.4	8.6	14.7	62.6	149.9	164.5	222.9	250.0	248.9	118.4	28.2	8.1	1,282	87.4
Central	5.4	21.3	34.2	85.8	158.8	166.9	183.6	190.3	271.3	189.3	53.4	7.8	1,369	86.5
Northeast	3.0	14.9	35.1	83.0	195.3	193.2	221.9	267.0	295.7	105.8	21.0	3.2	1,440	78.9
East	23.2	43.2	78.8	127.6	268.4	357.8	396.9	361.3	414.0	261.2	88.1	12.6	2,433	113.3
South	105.9	55.9	62.2	125.0	152.3	123.5	125.6	140.4	156.6	289.6	457.2	330.5	2,125	115.8

Source: Senanarong (1957)

*Komkris (1965)

1/ mm

Approximately 80% of the population is engaged in agriculture (Table 1.4). There has been a slight movement away from agriculture to other occupations, but this has generally been limited.

1.3.2. Density

The population for the overall country in 1970 was 69 habitants per sq.km. The highest density was 72 per sq.km in the rice growing Central region, and lowest 42 per sq.km in the Northern region (Anon, 1973). Bangkok, the capital, has a population of approximately 3 millions.

1.4 The Place of Timber and Particularly Teak in the National Economy

Thailand is an agricultural country. The agricultural sector is the most important source of the national income and approximately 80% of the population are engaged in agriculture.

1.4.1 Sources of the National Income

Thailand's major exports are primary products - agricultural crops, livestock, timber and fish (Table 1.5). In 1969 exports of these four commodities were valued at 10,338.40 million baht (1 baht = $A0.041) or 70.5% of the value of all exports (Changrien, 1972). The most important commodities are rice, rubber, tin and teak (see also Table 1.5). Rice in particular, has dominated the agricultural economy of Thailand for many years.

Consideration of gross domestic product (G.D.P.) over several years does however show the proportion contributed by the agricultural sector has declined from approximately 50 to 32% over the period 1951 to 1969, whilst there was a concurrent 12.8% increase in the industrial sector (Ingram, 1971).

Table 1.3 - Population projections, 1960-1980.

A. Total population size at certain dates (thousands)

Projection*	1960	1970	1980
1. C.F., M.M.D.	26,990	37,537	53,291
2. F.D., M.M.D.	26,990	37,069	48,508
3. C.F., R.M.D.	26,990	37,861	54,335
4. F.D., R.M.D.	26,990	37,381	49,449

B. Quinquennial population increase

	1960-65	1965-70	1970-75	1975-80
1. C.F., M.M.D.	18	18	15	20
2. F.D., M.M.D.	18	17	15	14
3. C.F., R.M.D.	18	19	19	20
4. F.D., R.M.D.	18	18	16	15

Source: Silcock (1967)

*C.F. = constant fertility, F.D. = fertility declining,

M.M.D. = moderate mortality decline,

R.M.D. = rapid mortality decline.

Table 1.4 - Manpower resource classified by major - grouping professions, 1967

Type-grouping of professions	Employed (millions)	Percentage of work force
Vocation and technical personnel	0.2	1.4
Administration and managers	0.07	0.5
Office clerks	0.19	1.3
Traders	0.99	6.8
Agricultural workers (including forestry)	11.62	79.9
Communication and transport workers	0.22	1.5
Ore and rock mines	0.03	0.2
Industrial process workers	0.91	6.3
Service personnel	0.32	0.21
Total	14.55	100.00

Source: Changrien (1972)

The economy of Thailand has improved considerably since 1961 when the government took an active role in economic development by proclaiming the National Economic Development Plan. During the First Plan (1961-1966) the gross national product (G.N.P.) increased by about 44%. This represented an average growth rate of 7.2% per annum, and was substantially higher than the 5% per annum of the previous decade (1951-1960). During the Second Plan (1967-1971), G.N.P. rose from 32.5 million baht in 1951 to 112.4 million baht in 1969 and per capita income from 1,743 baht to 3,239 baht (Table 1.6). The economic growth of the country has been derived mainly from the expansion of the agricultural sector and the targets drawn up for the Third Plan (1972-1976) (Table 1.7) indicate this trend will continue.

From the foregoing description, the stability and development of the Thai economy are heavily dependant on agriculture. The agricultural sector is expected to maintain its dominant role in the Thai economy for a long time (Changrien, 1972).

1.4.2. Contribution of Timber Products to the National Income

Forest products are a major source of government revenue. The revenue is derived from royalties, leasing fees and charges levied to cover forest improvement works, contractors, forest enterprises, and wood processing companies (Table 1.8).

With regard to particular timbers, teak is the most important, followed by Yang (Dipterocarpus spp), Teng (Shorea obtusa Wall), Rang (Pentacme suavis A.DC.), and Kiem (Cotylelobium lanceolatum Craib.). However, the revenue from

Table 1.5 - The value of selected export commodities in selected years (million baht)

Commodities	1950	1960	1966	1969
Rice	1,672 (48.2%)	2,570(29.8%)	4,001(28.0%)	2,945(20.0%)
Rubber	726(20.9%)	2,579(30.0%)	1,861(13.0%)	2,664(18.1%)
Tin	254(7.3%)	537(6.2%)	1,315(9.2%)	1,658(11.3%)
Teak	147(4.2%)	356(4.1%)	243(1.7%)	166(1.1%)
Fish (mostly shrimp)	21(0.6%)	16(0.2%)	235(1.6%)	321(2.2%)
Maize (unmilled)	-	551(6.4%)	1,520(10.6%)	1,674(11.4%)
Cassava	25(0.7%)	273(3.2%)	561(3.9%)	864(5.9%)
Tobacco	-	21(0.2%)	115(10.8%)	149(1.0%)
Oilseeds	93(2.7%)	170(2.0%)	277(2.9%)	224(1.5%)
Kenaf and jute	-	230(2.7%)	1,613(11.3%)	781(5.3%)
Bean and peas	12(0.3%)	56(0.7%)	185(1.3%)	243(1.7%)
Precious stones	19(0.6%)	20(0.2%)	97(0.7%)	150(1.0%)
Gunny bags	-	-	48(0.3%)	74(0.5%)
Total exports	3,473(100%)	8,614(100%)	14,166(100%)	14,722(100%)

Source: Ingram (1971)

teak is very much greater than from all others. Teak is specially important as an export earner. Table 1.9 shows teak products constitute over 50% by value of the forest products export from Thailand.

Apart from timber the minor forest products, oleoresin, shellac, gum damar, and charcoal are important forest products exports (Table 1.9).

The contribution of forest products to export income decreased from approximately 10% of the total exports of agricultural commodities in 1955 (Kantabutra, 1959) to 8% in 1958 and 1963 (Silcock, 1967). This trend is continuing. The foreign earnings of forest products were valued at 383.67 million baht in 1965, but only 275.60 million baht in 1970, a 28.2% decrease. Table 1.9 shows the fall in the value of teak exports over this period (1955-1970) to be of the order of 264.34 to 155.73 million baht.

The decreasing role of the forest products to the export income of Thailand is due to rapid rises in domestic wood consumption, the introduction of a national forest reservation programme, and a decrease of sizeable growing stocks due to deterioration of the forest estate from illicit cuttings.

1.4.3. Contribution of Teak Export to the National Income

Teak is considered to be one of the big four export which have contributed significantly to foreign earnings since the eighteenth century (Ingram, 1971). Before World War II Thailand's production of teak was approximately 35% of the world's total consumption (Kanchananaga, 1941, Kantabutra, 1959).

Table 1.6 - Gross national product in selected years during 1951-1969.

Year	In Current Prices	In constant Prices (1962)	Population	GNP per capita 1962 prices	GNP per capita current prices
	Billion baht		Million	Baht	
1951	29.8	35.2	20.2	1743	1475
1955	41.6	45.6	22.8	2000	1825
1960	53.9	56.0	26.4	2121	2042
1965	84.3	79.5	30.7	2590	2746
1969	130.8	112.4	34.7	3239	3769

Source: Ingram (1971)

Table 1.7 - Target for essential export commodities in 1976 (million baht) compared with the exports in 1972.

	1972	1976
Agricultural Products	2160	2880
Rice	2205	2490
Rubber	2400	3300
Maize	1260	1620
Tapioca products	930	1050
Kenaf	140	161
Mung bean	244	280
Tobacco leaf	288	432
Cattle-buffalos	80	100
Banana	29	49
Sorgum	105	128
Fishery Products		
Frozen shrimp	310	434
Other fishery products	389	598
Forestry products		
Teak	150	192
Others	80	98

Table 1.8 - Government revenue derived from principal classes of forestry products, 1950-70 (1,000 baht).

Year	Royalty			Income Fees	Fines	Sales of Wood Prod.	Forest Improvement Fees	Misc. Fees	Total
	Teak	Other Woods	Others*						
1950	1,064	8,158	4,891	900	236	5,693	5,217	7,529	34,264
1960	3,641	22,214	7,949	1,985	444	23,990	30,008	5,930	96,161
1970	6,146	41,306	8,713	15,401	1,080	21,566	54,187	42,234	152,633

Source: Anon (1972b)

* Firewood, charcoal and other forest products.

Table 1.9 - Export: Forestry products, 1955-1970.

Year	Teak	Yang	Other Woods	Others*	Total	Share of Teak (%)
		million baht				
1955	264.3	70.3	5.5	234.5	574.6	46
1960	356.1	89.3	12.7	93.0	551.1	65
1965	200.8	56.3	19.3	10.7	383.7	52
1970	155.7	13.0	39.4	67.5	275.6	56

*Yang oil, seedlac and sticklac, shellac, gum damar, firewood, charcoal.

Source: Anon (1972)

1.4.3.1 Foreign Earnings

Teak export rose rapidly in the later half of the 19th century with exploitation of teak forests by European firms. The major firms were British, French and Danish. The annual average teak export was 1.10 million baht in 1883-1887 and this rose to 11.90 million baht in 1905-1909, approximately 8% of the country's total export income at that time(Ingram,1971).

However, teak exports decreased during the next two decades. The depletion of growing stocks followed by a rise in domestic wood consumption from 37% in 1919 -1926 to 45% in 1930 (Ingram, 1971) resulted in a decline in the export of teak. During 1920-1939 the annual teak export accounted only 8 million baht or only 4% of the total commodity exports of Thailand.

After World War II, teak export still contributed approximately 4% of the total income derived from exports during 1947-1950. The long period of excessive exploitation had left the forests in such a poor condition, production levels fell to approximately 60% of figures for the previous two decades (1930-1948) (Komkris,1965). At this time domestic wood consumption continued to rise sharply. These two factors resulted in a decrease in the value of teak exports over the period 1955-1970 (Table 1.10).

Despite the fall in volume of exports the contribution of teak to the national income remains at approximately 200 million baht per annum, because of the rise in the world's market price of teak. Teak thus represents approximately half of the yearly national income from the forest products export (see Table 1.10).

1.4.4 The Future Trend of Wood Consumption and the Supply Potential of the Natural Forests

Recent work by FAO has forecast the consumption of forest products in Thailand over the period 1970-2000 (Table 1.11) (Cited by Koakamnerd, 1972). However, the present wood consumption calculated by Koakamnerd (1972) was much lower than that forecast by FAO (Table 1.11). Nevertheless, the wood demand must soon exceed the supply rate which the natural forests are able to sustain. Koakamnerd (1972) estimates the maximum annual yields from the existing natural forests as 3.0-3.5 million cu.m, of which 1.5-2.0 million cu.m could serve for construction wood. Therefore, the future wood requirements cannot be met from the natural forests alone.

1.5 Forest Resources

1.5.1 General

Forest land of Thailand comprises approximately 26 million ha (51.5% of the total land area) (Komkris, 1965). All forests in Thailand are government owned and forest protection, management and improvement are the responsibility of the Royal Forest Department.

1.5.2 The National Forest Policy

The general aim of the national forest policy, officially enunciated in 1960, is to manage the forest resources for the benefit and welfare of the general public. Within this general guideline, two major objectives are developed. Firstly to maintain a supply of forest produce for both domestic consumption and export, and secondly, to maintain forest cover for the protection of watersheds and non-wood values.

Table 1.10 - Share of the export in the output of teak in selected years during 1955-1970.

Year	Timber cut cu.m	Export cu.m	Percentage exported	Domestic uses
1955	305,878	87,878	28.7	71.3
1960	153,664	100,925	65.7	34.3
1965	201,814	45,223	22.4	77.6
1970	228,300	28,763	12.6	87.4

Source: Anon (1972b)

Table 1.11 - Consumption of forest products in 1970, compared with the FAO forecasts during 1970-2000.

Forest products	Consumption in 1970	FAO		
		1970	1985	2000
Sawnwood (million cu.m)	2.55	4.3	7.7	10.8
Poles (million cu.m)	0.33	1.5	2.4	3.0
Fuelwood (million cu.m)	2.14	50	70	85
Woodbased panels* (mt)	65,000	65,000	270,000	950,000

*including plywood, fibre-board and particle board.

Source: Koakamnerd (1972)

The reservation of 50% of the total land area of the country as permanent land (approximately 250,000 sq.km) was enunciated by the government as part of the First National Economic Development Plan (1961-1966). However, 50,000 sq.km will be taken from that area to serve the needs for agricultural land in the future (Komkris, 1965).

1.5.3 Forest Types and Distribution

The forests of Thailand, according to Komkris (1965) and Kemnark (1973), may be classified into two major types and several sub-types as follows:

The Evergreen Forest Type

(1) Tropical rain forest

(2) Hill evergreen forest

(3) Dry evergreen forest

(4) Pine forest

(5) Mangrove forest

The Deciduous Forest Type:

(6) Mixed deciduous (which may or may not include teak)

(7) Deciduous dipterocarps forest (Teng - Rang).

There are also two minor forest types, beach forest and swamp forest.

All forest types may be found throughout the country. However, the forests in the South, East and along the coast are predominantly the tropical rain forest and the mangrove. Deciduous dipterocarp forest predominates in the Northeast, and mixed deciduous forest in the North and Central regions.

1.5.3.1 Teak - Bearing Zone

Teak (Tectona grandis L.f.) grows naturally in mixed deciduous forest at the elevation of 100-750 m above sea level. The average temperature and rainfall is approximately 26.7°C and 1,200 mm per year respectively (Cornavich, 1967). Occurrence of teak forest is not limited by slope gradients, and the species is found mostly in limestone soil (Kemnark et al, 1972).

Teak forest is replaced at high elevations by coniferous forest (Pinus kesiya Royle ex Gordon, and Pinus Merkusii Royle.) and on lower hills and plain where the soil is lateritic or dry by deciduous dipterocarps forest (Florence, 1972). Teak forest is generally open in nature with teak growing singly or in small group mixed with deciduous trees (e.g. Pterocarpus macrocarpus Kurz., Afzelia xylocarpa Criab., Lagerstroemia calyculata Kurz.) and bamboos (e.g. Bamboosa arundinaceae Willd., Cephalostrachyum pergracile Munro., Thyrsostrachys siamensis Gramble).

The major teak forests occur in the North and Central regions (Komkris, 1965) mainly in the North (Figure 1.1). The forest covers approximately 92,000 sq.km or 28% of the total forest land (Corvanich, 1967). The northern teak-bearing zone constitutes most of the area north of the Tanoasee Range the natural border line between Thailand and Burma. In the Central region teak occurs mainly along the range north of Kanchanaburi Province (Figure 1.1).

1.6 Teak Forest Management in Thailand

Prior to 1896 teak forests were privately owned and inherited from generation to generation and were therefore completely in the hands of the local Chiefs and Chaos (Royal family) of the Northern semi-independent states (Banijbhatana, 1971). There was no control over the exploitation of the teak forests; undersized trees were frequently cut during hasty and indiscriminate felling, and no planned replacement was undertaken. The working of teak forests was irregular and that the principal of conservation for perpetuating the yield was not followed (Banijbhatana, 1962; Komkris, 1965; Ingram, 1971). In 1896, to remedy this situation and to have a stricter control over teak resource the government took over management of the teak forests.

The development of teak forest management in Thailand followed the pattern of the Forest Services of India and Burma (Banijbhatana, 1962). Systematic management of teak forests began with the setting up of a 12 year felling cycle for teak exploitation by teak leases. In 1908 the felling cycle was increased from 12 years to 30 years as the 12 year cycle was too short.

Under the system, a felling series was divided into two blocks, with one block opened for working for a period of 15 years, and the remaining block closed for the same length of time. At the end of 15 year lease, the block positions were reversed. Trees over girth limit of 2.13 m were cut except for 15% of sound trees reserved for silvicultural reasons, particularly seed production. Isolated seed trees were generally retained in the system.

In 1953 the system was improved. Each teak forest was divided into 40 felling series. Each felling series was of approximately 100-500 sq.km and was roughly divided into 30 felling coupes of more or less equal size. Only one coupe was open for working in each year. By this system the yield was regulated partly by area and partly by the number of trees selected and marked in the opened annual coupe.

Despite these detailed control plans the teak forest condition is frequently very poor. The reasons are:

(1) Illicit cutting encouraged by the high market prices of teak.

(2) The ineffective policing of forestry law by the authorities.

(3) Local needs for agricultural land. This is especially important for the hill-tribes practicing shifting cultivation in the northern teak bearing zone (Anon 1959 ; Komkris, 1965; Florence, 1972).

A report on a forest inventory of the teak bearing-zone in northern Thailand by Loetch (1957) revealed that in 1957 shifting cultivation and illicit cutting had reduced the former area of teak-bearing deciduous forest by more than half. In addition, only one-third of the mountainous forest remained, the rest having been destroyed. This report was supported by Komkris's (1965) investigations. Komkris noted that approximately 2 million ha of the forests of the northern teak zone had been severely damaged during the past two decades. He estimated that growing stocks of 1.3 million teak trees of exploitable size in 1930-1948 had decreased to approximately 300,000 trees in 1954-1970, or about 6 million cu.m had illegally disappeared out of a possible total of 8 million cu.m. Anon (1973) confirmed that if forests had been well protected, forest yields should have been ten times the current production.

1.7 Teak Plantation Programmes

1.7.1 The Importance of Teak Plantation Establishment

It is clear from the previous discussions that teak plantation forests can benefit the national economy in the following ways:

(1) by alleviating future wood deficiencies and by replacing import of timbers,

(2) by earning from teak exports,

(3) by providing a base for the establishment and enlargement of wood producing industries and incidentally, by providing out-of-season employment for rural workers,

(4) by putting deserted shifting-cultivation land, devastated teak forest, and other land of low productivity to productive use,

(5) by increasing the government's revenue from taxation,

(6) by providing important secondary benefits, such as social benefit of recreation and amenity facilities, protecting watersheds and catchment areas, preserving local climate, habitats for wildlife, etc.

Thus whilst the main purpose of teak plantation programmes is the production of wood, they can also yield other benefits.

1.7.2 Development of Teak Plantation since 1906

1.7.2.1 Early Stage of the Establishment

The first teak plantations were established under agricultural plantation or "Taungya" system at Prae Province in 1906 (Namwong, 1968; Kemnark, 1973). These initial plantations were set up as trials on deserted areas of shifting cultivation. In 1943 more extensive teak plantations were established throughout the Central and Northern region (Samaputti, 1973). Planting areas have been further increased since 1953, and up to 1960, however nearly 6,000 ha of teak plantation distributed throughout central and northern Thailand. ?

1.7.2.2 The First National Economic Development Plan (1961-1966)

Establishment of teak plantation was emphasised on the First National Economic Development Plan. The planned annual target was fixed at 800 ha and at the end of 1966 5,354 ha throughout northern and central Thailand was reforested. However, the annual planting was insufficient to match the future increase in population and wood needs, especially with the devastation of forest land and an annual planting of 1,600 ha was recommended (Anon, 1964).

1.7.2.3 The Second National Economic Development Plan (1967-1971)

The target for teak planting by the Royal Forest Department during the Second Plan was 13,200 ha over the period and at the end of the Plan 13,517 ha had been planted despite some financial problems in 1968 and 1969.

1.8 Expansion of the Programmes

Up to 1972 a total of 29,500 ha of teak plantation had been established (Kemnark, 1973; Anon, 1973). The total area of new plantation for all forest products as recommended by the FAO to meet the future wood consumption would be 3 million ha by 2005 or 81,000 ha annually from 1976 onwards.

An attempt is being made to increase the present annual planting from the 5,000 ha established in 1972. Under this project two-thirds of the plantation will be teak. From 1975 onwards each annual teak planting will be 1,000 ha in 100 planting units.

Plans are for the planting programmes to be 20,000 ha annually during 1985-1994 and 40,000 ha annually after 1994.

1.9 Summary

The decline in teak export will continue. The depauperate condition of teak resource and the soaring of domestic wood requirements will affect teak export in the future. To date teak timbers both for domestic uses and for export have been wholly derived from exploitation of natural teak forests. Young teak plantations have so far no production to compensate for the deficiency of the natural forests (Samaputti, 1973).

Thus the potential supply of teak is being rapidly reduced. As domestic needs are increased (over 80% of annual teak produced) there will be a gradual decrease in teak available for export. The role of teak in the national income or in the economy as a whole may decline in the near future. Teak plantation programmes to compensate for this situation will become more and more necessary.

To improve the quality and yield of the plantation intensive teak improvement programmes including breeding, silviculture and nursery research were established in Thailand in early 1965(Keiding, 1966). During the past ten years important progress has been made in establishment of provenance trials, clonal seed orchards and seed production areas by the Teak Improvement Centre (TIC) (Hedegart, 1974).

The importance of provenance trials will be discussed in the next chapter.

CHAPTER 2

Provenance Variation in Teak (*Tectona grandis* L.f.)

2.1 Introduction

A knowledge of provenance variation is essential for any major tree breeding programme. Such knowledge indicates relative value of material from different seed sources. In particular, value of the local sources can be determined (Wright, 1962; Callaham, 1964, 1970; Burley, 1966; Lines 1967).

This chapter reviews provenance variation in teak. Initially, the natural range of the species and the environmental factors limiting are described, followed by the variation pattern and degree of the differences observed in the natural stands. Finally provenance variation observed in provenance trials in five countries is detailed.

2.2 The Natural Distribution of Teak and Factors Affecting the Occurrence of the Species

2.2.1 Natural Distribution of Teak

Teak is indigenous to Southeast Asia but discontinuous in occurrence (Imam, 1970). The species occurs through the greater part of Burma, the Indian Peninsular, northern and central Thailand and north-western Laos (Haig et al.,1958; Streets, 1962; Komkris, 1965) (Figure 2.1). Cambodia, formerly thought to be a natural habitat of teak (Haig et al., 1958; White and Cameron, 1965; Persson, 1971b) is evidently outside the species natural occurrences (Gyi, 1972).

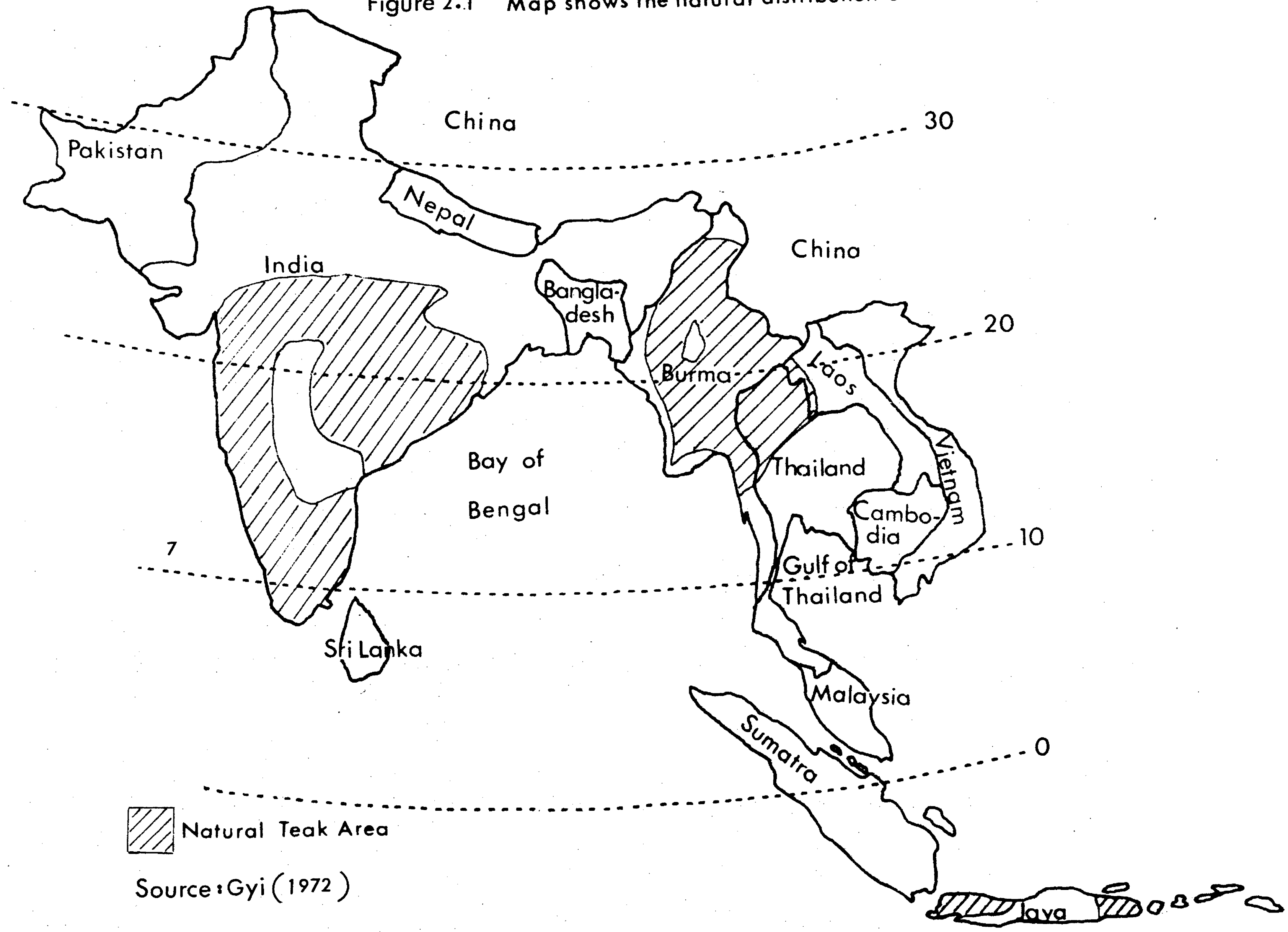
The species is also found just south of the equator in Indonesia (Java and Muna) where it has been stated to be natural (Haig et al., 1958; Little and Wadsworth, 1964; Wood, 1967; Keiding, 1973; Samaputti, 1973) but it is also thought to have been introduced to the area some 350 years ago or more (Beard, 1943; Streets, 1962). It has also been reported that teak was introduced to Indonesia by Hindus in the seventeenth century (Howard, 1948; Letourneux, 1957; Alphen de Veer, 1957). Thus, Indonesia has been considered as outside the natural occurrence of the species (Anon, 1957; Anon, 1958; Streets, 1962; Gyi, 1972). However, there is clear agreement on the presence of teak in Indonesia for many years. The area should therefore be considered as an independent seed source. Even if teak was originally introduced to Indonesia it must now be sufficiently modified to be regarded as a separate seed source (Gyi, 1972).

Teak's natural habitat lies between 25°30'N on the northern limit and on the southern limit between 9°N on the west and 16°30'N on the east (Anon, 1959). On the east it extends to a longitude of 104° 30'E and on the west to 73°W (Anon, 1958; Streets, 1962; White and Cameron, 1965).

With regard to altitudinal limits, teak extends from sea level to 1,216 m (White and Cameron, 1965) or rather more (as in Coorg, central India) (Anon, 1958; Streets, 1962). However, natural habitats are limited in Thailand to 750 m (Banijbhatana, 1971; Kemnark et al, 1972) and in Burma to 914 m (Gyi, 1972).

Within the habitats teak grows in isolated tracts, often of considerable extent, usually in hilly or undulating country but sometimes on plains and alluvial flats (Troup, 1921; Ross 1961; Kermode, 1964).

Figure 2.1 Map shows the natural distribution of teak



Source: Gyi (1972)

2.2.2 Climatic Requirements of the Species

2.2.2.1 Rainfall

Teak grows in a climate which ranges from dry to moist tropical with annual rainfall variation from 625 mm to 5,000 mm (Anon, 1958; Streets, 1962). Optimum rainfall appears to be between 1,270 mm to 1,650 mm (Kermode, 1964) and teak quality is low in both drier and wetter regions. Development of teak under low rainfall conditions is very poor (Anon, 1958; Gyi, 1972). Teak occurring in dry localities (635 - 760 mm) is small, stunted and crooked with a maximum height of 8-9 m (Gyi, 1972). In a moist tropical region (5,080 mm) teak is large but badly fluted and of poor quality.

Rainfall distribution is also an important factor determining the distribution and performance of teak. Teak requires a seasonal or monsoonal climate with a well-marked dry season. Gyi (1972) emphasized the importance of rainfall distribution throughout the species' natural occurrence (Table 2.1, Figure 2.2 and 2.3); the definite dry season is characteristic. Teak is normally leafless throughout the greater part of the dry season, usually from November to April. When the rainfall is abnormally heavy in the dry season the trees fail to shed their leaves and their growth is checked (Bellouard, 1956; Streets, 1962). Thus a well-marked dry season with at least two months (Mensbruge, 1956) to five months (Anon, 1958; Streets, 1962) of rainfall of approximately 60 mm (Anon, 1958) is essential for satisfactory successive growth of teak as well as the success of the introduction of the species. Failure or unsatisfactory results of exotic teak plantations in areas without a well-marked dry season have been reported in lowland

Ivory Coast (Bellouard, 1956), Malaysia and North Borneo (Streets, 1962).

2.2.2.2 Temperature

Through its natural habitats teak is subjected to markedly varying temperature regimes (Table 2.2, Figure 2.2, 2.3). Within the natural habitats the mean monthly temperatures range between 22 and 33^{o}C. In Thailand temperatures recorded in the teak zone are shown in Appendix 2. The absolute mean monthly maximum temperature is 43^{o}C and the absolute mean monthly minimum 5^{o}C. The best growth development appears within 12.5^{o} and 40^{o}C (Haig et al., 1958) or 43.3^{o}C (Streets, 1962; White and Cameron, 1965).

Teak cannot stand frost (Haig et al., 1958; Kermode 1964; Gyi, 1972). Thus the natural occurrence of the species is limited to mostly frost free area.

However, frost tolerance of teak at the northern limit of its natural range was reported by White and Cameron (1965) and teak does survive when grown in frosty areas outside its habitats (Streets, 1962). In the Union of South Africa teak has been reforested at elevations of 1,036 m with light frost. At the age of 27 years mean height growth was 7.6 m and diameter 13.1 cm. This shows the species adaptability to frost but nevertheless growth and form are poor under these conditions.

2.2.2.3 Daylength

Daylength is likely to be of minor importance in controlled development and growth of teak (Gyi, 1972). Gyi studied the effect of photoperiod of 8, 12 and 16 h on the development of teak seedlings. He found relative growth rate (RGR) was unaffected by photoperiod, the net assimilation rate

Table 2.1 - Monthly rainfall distribution for selected stations in the natural teak zone.

Location	Lat.	Alt. (m)	Mean Monthly rainfall (mm)												Mean annual rainfall
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
India															
Bombay	18°54'N	11	3	3	3	*	18	485	617	340	264	64	13	3	1813
Madras	13°04'N	16	36	10	8	15	25	48	91	117	119	305	356	140	1270
Cochin	9°58'N	3	23	20	51	124	297	724	592	353	196	340	170	41	2931
Burma															
Myitkyina	25°23'N	145	10	23	23	46	160	480	478	434	257	183	38	13	2145
Toungoo	18°56'N	48	5	5	8	53	203	366	455	480	297	183	48	10	2113
Thailand															
Chiengmai	18°47'N	314	*	10	8	36	122	112	213	193	249	93	30	13	1079
Laos															
Vientiane	17°58'N	162	5	15	38	99	267	302	267	292	302	109	15	3	1714
Indonesia															
Pasuruan	7°38'S	5	226	279	213	137	94	56	25	5	5	18	61	165	1284

* less than 2.5mm

Source: Gyi (1972)

Table 2.2 - Mean monthly temperature for selected stations in the natural teak zone.

Location	Lat.	Alt. (m)	Mean monthly temperature (°C)												Mean Annual temperature
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
India															
Bombay	18°54'N	11	24	24	26	28	30	29	27	27	27	28	27	26	27
Madras	13°04'N	16	24	26	28	31	33	33	31	31	30	28	26	25	29
Cochin	9°58'N	3	27	28	29	30	29	26	26	26	26	27	28	27	27
Burma															
Myitkyina	25°23'N	145	17	19	23	26	28	27	27	27	28	25	22	18	24
Toungoo	18°56'N	48	22	24	29	31	30	28	27	27	28	28	26	22	27
Thailand															
Chinegmai	18°47'N	314	21	23	26	29	29	28	27	27	27	26	24	21	26
Laos															
Vientiane	17°58'N	162	21	24	26	28	28	28	27	28	27	26	24	22	26
Indonesia															
Pasuruan	7°38'S	5	27	27	27	27	27	26	26	26	27	28	28	27	27

Source: Gyi (1972)

Figure 2.2 - Climatograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in the natural teak zone.

Source: Gyi (1972)

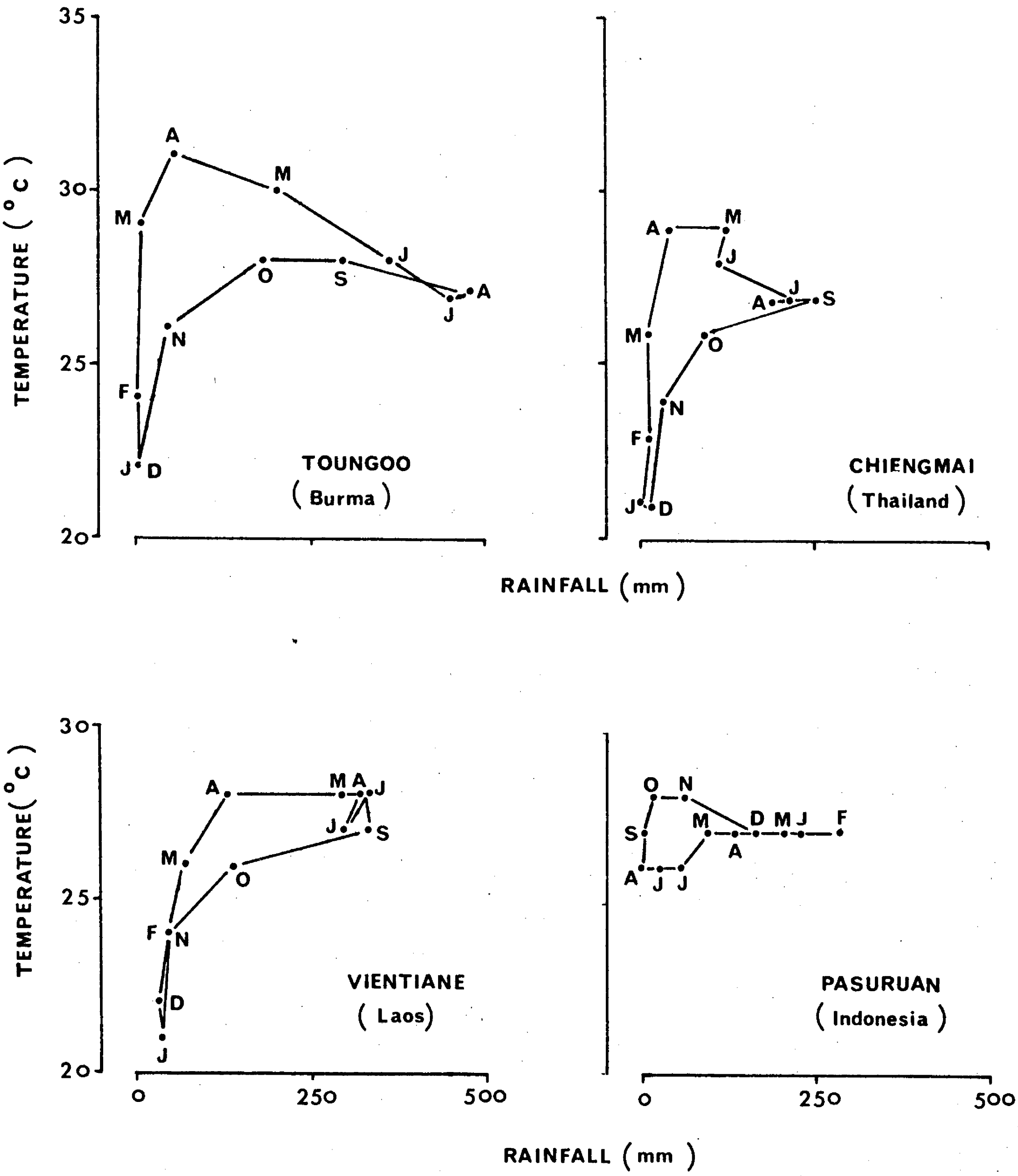
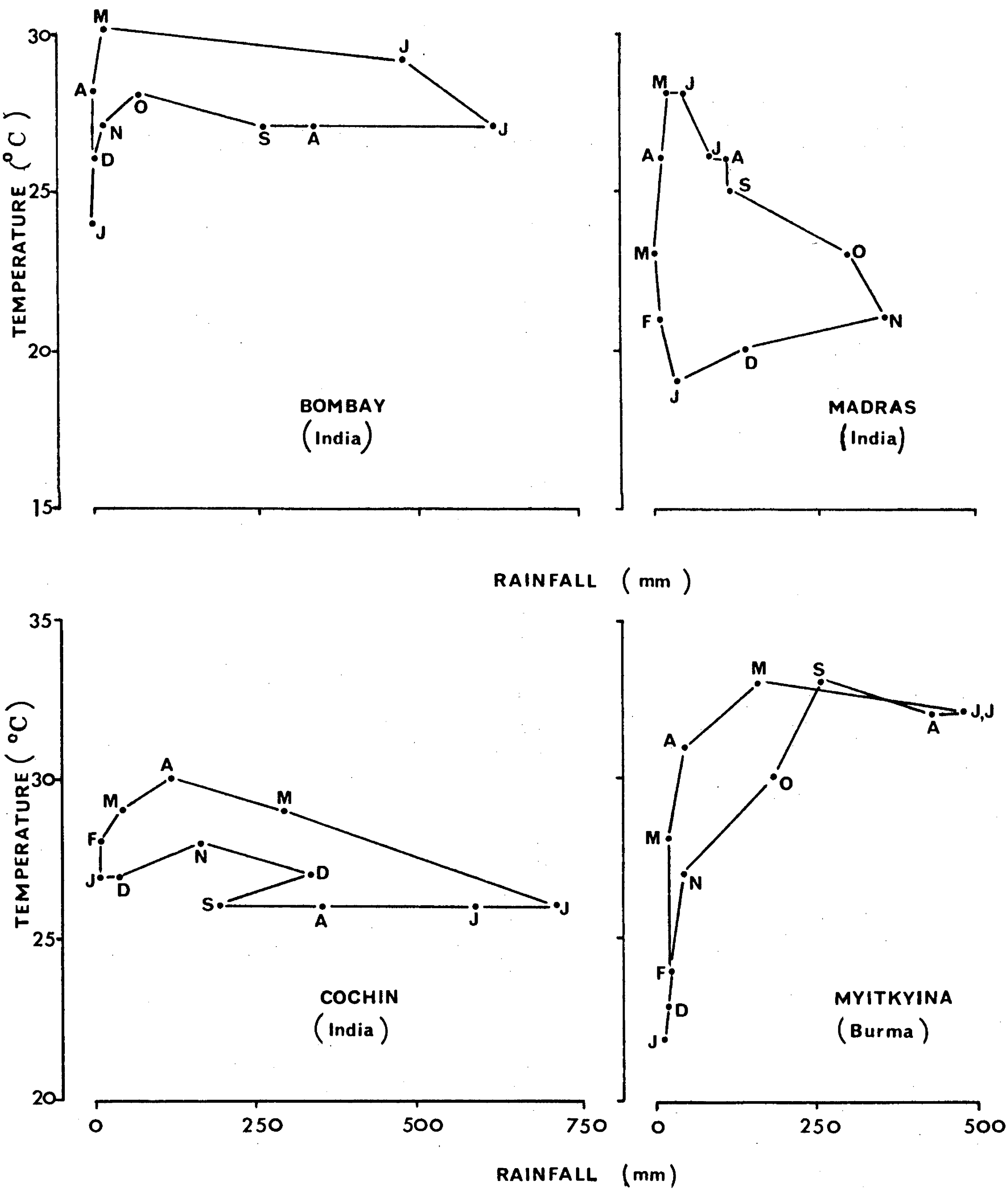


Figure 2.3 - Climatograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in natural teak zone.

Source: Gyi (1972)



(NAR) was greater at longer days while leaf area ratio (LAR) showed a reverse trend. Height growth was greater the longer the days. However, in all cases a response to photoperiod was demonstrated only between 8 and 12 h, and the difference in response between 12 and 16 h was not significant. Since the day-length in natural teak zone exceeds 12 h (Gyi, 1972) and there are only small variations in daylength in the tropics (Lowe, 1968) teak is therefore unlikely to be markedly affected by daylength fluctuations.

Growth of teak is, however, affected by variation in light intensity. Nwoboshi (1972) studied responses of teak to various light intensities, namely 100%, 75%, 53% and 25% of full daylight. The results are given in Table 2.3. He found dry matter increased with reduction in light intensity down to 75%. Straight teak seedlings showed best height growth under full daylight, while teak stump seedlings showed this performance at 53% daylight. The stump seedlings produced maximum leaf area under 53% light intensity. Similarly, Bhatnagar (1966) found height growth of teak seedlings was greatest at 94% of full light (14.3cm), followed by 100% (13.0cm), 22% (10.8cm) and 9% (7.8cm) light intensity respectively. Direct correlation was also found between height growth and plant dry weight of the seedlings.

These studies indicate that although teak is essentially a light demanding pioneer species (Anon, 1958), it achieves best development with some degree of shading during seedling stage. This is at variance with the conclusion that the species cannot tolerate any shading at any stage of its life (Troup, 1921; Marshall, 1929; Anon, 1958) but in agreement with

Table 2.3 - Influence of light intensity on dry matter production, height growth and leaf area of teak seedlings.

Parameter	Type of* seedling	Relative light intensity(%)				Critical difference at P.05
		100	75	53	25	
Total dry weight (gm)	A B	47.7 5.21	78.18 14.63	67.48 10.98	21.53 0.61	8.76 0.76
Height growth (cm)	A B	28.50 13.00	55.15 10.66	66.60 10.33	30.10 7.00	15.61 NS
Leaf area (cm^2)	A B	2990 760	5700 810	6000 1000	330 90	214 NS

*A = Teak stump

B = Teak seedling

Source: Nwoboshi (1972)

those of Kadambi (1957), Takle and Mujumdar (1957) and Wyatt-Smith (1967) who stated that teak seedlings do benefit from some shading.

2.2.3 Edaphic Requirements of the Species

2.2.3.1 Geology

Teak occurs on a wide variety of geological formations and rock types. These include limestone, granite, gneiss, schist, sandstone, conglomerate, shale and igneous Decantrap, the major Indian rock formation associated with teak (Kulkani, 1951; Puri, 1951; Hewetson, 1956; Banijbhatana, 1957, 1971; Seth and Yadav, 1957; Takle and Majumdar, 1957; Haig et al., 1958; Streets, 1962). However, whilst teak does occur on soil overlying conglomerate, sandstone or laterite, it will not grow well in such localities. Indeed, it may be absent from such soils (Kadambi, 1957; Seth and Yadav, 1957; Takle and Majumdar, 1957).

2.2.3.2 Soils

Teak grows best on deep, well-drained, moist sandy loam of moderate to high fertility (Streets, 1962; Anon, 1972a). Most teak forests are found on slopes with good sub-soil drainage and growth of teak is noticeably more vigorous at the foot of the ridges than on tops (Griffith and Gupta, 1947; Gyi, 1972). Alluvial flats along streams may carry heavy stocks of the best teak if the drainage is good (Griffith and Gupta, 1947; Seth and Yadav, 1957; Takle and Majumdar, 1957; Streets, 1962). This is observed in natural forests in Thailand (Anon, 1972a) and in high quality teak plantations in Burma (Gyi, 1972).

Teak will not tolerate water logging or stiff clayey soils (Marshall, 1929; Kadambi, 1957; Gupta, 1957; Takle and Majumdar, 1957;Stevens, 1970) or sites liable to prolonged inundation, nor does it grow on laterite, black cotton soils, and deep dry sand (Streets, 1962).

Teak usually occurs on soils with a pH within the range of 6.5 to 7.5. Below pH 6.0 teak is completely absent and above pH 8.5 growth is poor (Kulkani, 1951). Similarly, Jingsoongneon (1967) found soil in natural teak forests at Lampang, Thailand had pH ranging from 6.1 to 7.3.

However, usually lower pH values are present in teak plantations; 5.5-5.8 in Nilambur, India (Gupta, 1951) and 4.0-6.0 Laos (Stevens, 1970).

2.3 The Variation Patterns of Teak

2.3.1 Variation in Natural Stands

The following reviews consider the intraspecific variation recorded in morphological and anatomical structures in the species.

2.3.1.1 Variation in Seed Character

Teak produces a hard woody fruit containing up to four seeds. The fruit is however frequently and commonly referred to as the 'seed' and this will be done in this thesis.

Seed coat (calyx) of teak varies and this character is heritable (Larsen, S. cited by Kittinanda, 1968). Teak seed varies in size. The diameter of the inflated calyx may be as much as 38.1 mm in Burma (Kermode, 1964) while a 10.5-11.5 mm is noted to be the normal size in Thailand (Bryndum, 1966).

Seed quality of the species varies between localities (Imam, 1970). Seed from (a) Central Burma (21^{O}N), from (b) lower Burma (17^{O}N) and from (c) North Burma (25^{O}N) were compared by Kermode (1964). From three years' consecutive germination testing he found the germination capacity of the seeds from central and lower Burma (40-50%) did not differ significantly, but seeds from northern Burma gave inferior results (20% or less).

Sen Gupta (1937) carried out germination tests on seed from various parts of India. He found the seed size and germination capacity of Indian seeds varied between localities and:

(a) seeds from two moist areas gave better germination and germinated more quickly than seeds from other sources.

(b) Seeds from dry localities gave poorer results.

(c) Seeds from Bombay, both from moist and dry localities were of the worst quality.

Hedegart (1971a) compared size, weight and germination percentage of seed from 15 sites in Thailand. He found size and weight of the seed varied considerably; size range from 9.9 - 12.4 mm (mean = 11.2 mm), and weight of 1,000 seeds from 383 - 637 gm (mean = 522 gm). Seed size and seed weight were highly significantly correlated (r = 0.94). Germination percentage was significantly correlated to size (r = 0.57) and to weight of seed. Germination percentage showed no latitudinal variation, covering from 14^{O}N to 27^{O}N.

2.3.1.2 Variation in Flowering Habit

In teak the first inflorescence generally develops from the apex of the terminal shoot of the tree (Gram and Larsen, 1958; Haig et al., 1958; White, 1962; Boonkird, 1966; Larsen, 1966). This flower formation causes disturbance to the otherwise straight axis of the tree, causing the dieback of the leader, and the development of severe forking leading to the subsequent forming of a broad crown (Gram and Larsen, 1958; Boonkird, 1966; Larsen, 1966). Therefore, the appearance of the first flowering phase in teak determines the attainable length of the clean and straight trunk (Gram and

Larsen, 1958; White, 1962; Larsen 1966).

The age at which the first flowering of teak differs. Teak generally flowers quite early at age 5 or 6 y, but in some places it may flower at 2 y (Boonkird, 1966). Whilst first flowering at ages 10-15 y can be found in teak plantations, this is considered the latest flowering age of the species (Boonkird, 1964; Larsen, 1966; Kittinanda, 1968).

Early and late flowerings in teak are variable among the individuals and are under genetic control (Gram and Larsen, 1958; White, 1962; Cameron, 1966, 1968; Boonkird, 1966; Larsen 1966). The assessment of this variation is demonstrated in clone collections (Boonkird, 1966; Larsen, 1966).

Although the age of the first flowering of teak is clearly under genetic control, environmental factors have been reported as causing a delay in the initial flowering. Kermode (1957) believed early flowering was hastened by unfavourable site conditions, whilst Keiding (1966) reported light deficiency could cause early flowering.

2.3.1.3 Variation in Wood Quality

Teak wood varies in properties between geographical zones. Indian teak is paler in colour with fewer stripes, heavier in weight and of a different chemical composition than Burmese and Thai teak (Samaputti, 1973). Nair and Mukerji (1960) studied natural-grown teak from Indian and Burmese sources (eight from India, three from Burma) in four localities for a range of wood properties. (see Table 2.4). Analysis of variance showed significant differences between trees from the same locality and between the mean values in different localities for all properties studied.

Table 2.4 - Variation in physical and mechanical properties of natural-grown teak. (M of R = Modulus of Rupture, M of E = Modulus of Elasticity)

Locality	Specific gravity	Rings/inch	Max. crush stress (lb/sq.in)	M of R 1000 lb/sq.in	M of E 1000 lb/sq.in	Max. of height of drop in inches
1. North Kanara, Bombay	0.555	0.5	5320	11100	1515	37.0
2. North Kanara, Bombay (girdled)	0.563	0.7	4770	9600	1365	30.7
3. North Kanara, Bombay (ungirdled)	0.523	1.0	4570	9350	1310	32.3
4. Westhana, Bombay	0.576	0.8	5430	10900	1445	39.3
5. Piynmana, Burma	0.613	0.5	7520	14350	1950	41.3
6. Zigon, Burma (girdled)	0.593	0.3	6450	12100	1810	36.9
7. Zigon, Burma (ungirdled)	0.588	0.6	5690	11450	1645	35.3
8. Hoshangabad, M.P.	0.522	1.2	5210	10350	1400	35.0
9. South Chanda, M.P.	0.527	1.6	4480	9100	1205	27.5
10. Malabar, Madras	0.615	0.9	5470	10750	1570	31.8
11. South Coimbatore, Madras	0.642	2.6	6340	12500	1490	34.2

Source: Nair and Mukerji (1960)

Teak wood quality shows altitudinal variation. Sekhar et al.(1960) showed mechanical properties of natural teak from five forests in India and Burma varied from location to location.

2.3.1.4 Variation in Drought and Frost Tolerance

Teak seedlings are sensitive to drought (Anon, 1958; Takle and Gyi, 1972). . The teak of India shows more drought-tolerance than the teak from northern Thailand and northern Burma (Anon, 1957) of which the latter requires a fairly high degree of humidity and does not tolerate a water vapour tension below 60% during the dry season. The Indian teak tolerates longer and more intense dry season with a water vapour tension as low as 30%.

Kedharnath and Matthews (1962) summarized the general patterns of drought tolerance and growth habit originated from moist and dry type teak seeds. On moist sites, the trees from moist zones showed faster growth and better growth habit than those from dry zones. This pattern was reversed on dry sites as those from dry zones showed more tolerance of poor soil, longer dry season and low air humidity.

Teak is susceptible to frost (Gupta, 1957; Takle and Majumdar, 1957; Haig et al., 1958). Gupta (1957) reported seedlings from North Bombay suffered to frost markedly more than those from North Burma, South Burma, Nilambur and South Bombay.

Frost tolerance of teak is heritable (Kedharnath and Matthews, 1962). Selection of teak for this character are possible and this is being carried out in India. Progress of this work will reveal the variation patterns of this character.

2.3.2 The Existence of Teak Races

The foregoing reviews indicate teak varies in important characters both within and between regions. However, no comprehensive analysis of character variations has been made yet. Several countries recognize variation within the species for commercial purposes. Although these are practical distinctions and not scientifically based, they are nevertheless effectively wideranging studies of variation and give further indications of variation patterns.

The characteristics of five races from Thailand are detailed here and the existence of similar races in India and Burma noted.

Five races have been morphologically classified in Thailand (Mahaphol, 1954; Boonkird et al, 1962; Kemnark and Boonkird, 1963; Kittinanda,1968). The Thai teak races are named as follows:

1. Sak Tong (Golden Teak).
2. Sak Hin (Rocky Teak).
3. Sak Yuak (Soft teak).
4. Sak Khi Kwai (Dark-green teak).
5. Sak Khai (Waxy teak).

Variation in morphological characters has been investigated and the results obtained are given in Table 2.5. These races differ in both external and internal morphology.

Occurrence of the Thai teak races is related to edaphic conditions, for example, Sak Tong and Sak Yuak are found only in rather deep sandy loam or clay loam soils with high moisture content. In soil containing limestone, separation into the different races becomes impossible (Kemnark and Boonkird, 1963).

The teak races show no statistically significant differences in chemical and physical properties of wood. Sak Tong material shows some variation when tested under green conditions (Sono, 1959). However, these results have not been firmly accepted due to the uncertainty of the wood samples studied (Boonkird et al., 1962).

Variation in growth of these five races is being investigated clonally by the Teak Improvement Centre (TIC),Thailand (Hedegart, 1972). Variation in height and diameter growth (Table 2.6) seemed to be exhibited, but so far the results are inconclusive.

It is of interest that black streak (a highly prized figuring) occurs in all the Thai races (Boonkird et al., 1962; Kemnark and Boonkird, 1963). To date the black streak as a separate race is being investigated. However, it may be that there are six races including black streak teak as the sixth (Boonkird et al.,1962; Kemnark and Boonkird, 1963).

Similar racial classifications have been detailed for India (Kadambi, 1960; Rajasingh, 1960; Kedharnath and Matthews, 1962) and Burma (Gyi, 1972).

In summary, teak shows ecotypic variation in both external and internal morphology as well as growth habit.

2.4 Variation in Provenance Trials

The foregoing descriptions have shown between-and within-tree variation in various characters of teak. These variations observed mostly among natural stands are phenotypic and not necessarily genetic. The genetic portion of the regional variation can only be assessed in provenance trials.

Table 2.5 - Preliminary observations of external and internal morphology of five teak races in Thailand.

Race	Outer bark	Sapwood	Heartwood	Other characteristics
Sak Tong (Golden Teak)	Deep fine fissures finer than Sak Hin, the fissures are long, not as much network between cracks as in Sak Hin.	Thick, and annual rings distinct.	Clear annual rings, many rows of pores dark brown when cut.	The wood is golden brown in colour, orderly arranged, not brittle, intermediate hardness as between Sak Hin and Sak Yuak.
Sak Hin (Rocky Teak)	Mostly deep wide fissures, there are networks between the cracks.Sometimes it has rather smooth bark with very shallow cracks.	Rather thick and annual rings are distinct.	Green cut shows darkish brown but dry cut shows grayish yellow. The wood is harder than other teaks.	The wood shows fine grain in tangential and radial section.
Sak Yuak (Soft Teak)	Flat, thin bark, fine fissures, networks present between the fissures, the cracked bark does not bend or peel off at the upper end.	Annual rings in the region near cambium are not distinct and the softwood is rather thick.	Clear annual rings, yellowish brown in colour, new cut shows grayish yellow.	Narrow region of springwood in heartwood, there are only 2 lines of pores, wood soft and easily cut.
Sak Khi-Kwai (Dark-green teak)	Very flat bark, shallow fissures as in Sak Yuak, but the cracked bark are often short scaled and dark in colour.	Its thickness is the same as Sak Yuak but the annual rings are not distinct.	One or two lines of pores in the annual rings. The region near sapwood annual rings are not clear.	The wood is grey in colour at the new cut. It shows greenish dark when it is green. The wood is brittle and easily breaks off The colour is the same as Sak Yuak when it is dry.

Table 2.5 (Contd)

Race	Outer bark	Sapwood	Heartwood	Other characteristics
Sak Khai (Waxy Teak)	Flat, thick bark, but always cracks in deep, wide rows.	Thick, only four annual rings are clear.	Clear annual rings springwood is wide and yellowish brown in colour.	Waxy when touched, the wood is soft as Sak Tong. The knife blade that use to cut will feel waxy too.

Source: Boonkird et al.(1962). Unpublished.

Table 2.6 - Height and diameter growth of five Thai teak races at age 10 y (Hedegart, 1972).

	Height (m)	Diameter (cm)	No. of ramets
Golden teak	14.4	15.8	8
Rocky teak	18.1	14.9	8
Soft teak	12.3	14.6	10
Dark-green teak	15.0	17.1	10
Waxy teak	12.9	13.4	8

Source: Hedegart (1972).

There are numerous established provenance trials of teak in various countries. These include trials in Ceylon (streets, 1962), New Guinea (Cameron, 1966, 1968), Malaysia (Wyatt-Smitth, 1957, 1961), Trinidad (Beard, 1943) and Fiji (Streets, 1962). The more detailed trials have been established in Indonesia (Coster and Eidmann, 1934; Beard, 1943; Becking, 1951 ; Alphen de Veer, 1957; Anon, 1958), Burma (Maung Gale (2) and Nyunt Naing, 1967), India (Mathauda, 1954) and Thailand (Hedegart, 1971, 1974) and these are reviewed in this section.

2.4.1 Indonesia

In 1932 test plantations were established at several places in Indonesia with seven provenances from Indo-China, Thailand, Burma, Malabar (India), Central province (India), Godavari (India) and from local stands. The results of this trial have been reported by Coster and Eidmann (1934), Beard (1943), Becking (1951), Alphen de Veer (1957) and Anon (1958).

After 21 years of age growth and form of the trees showed distinct differences. The local and Malabar (India) provenances showed the best height growth and those from Indo-China and Thailand had the best form with slight branches, though Burmese material was only slightly inferior. The trees from Central province (India) and from Godavari (India) showed poor growth and bad shape with heavy branching.

There appeared to be some evidence of provenance x site interaction. In East Java, with a marked dry season, trees from Thailand showed more tolerance to droughting than indigenous provenances (Becking, 1951). However, no full reports of these are available.

2.4.2 Burma

Trees from four exotic and nine local seed lots were planted in replicated trials at three locations in southern Burma (Zigon, Pyinmana and North Toungoo) (Maung Gale (2) and Nyung Naing, 1967, cited by Gyi, 1972). No planting date was mentioned. The exotic materials were from Indonesia, India, Togo (Dahomey) and New Guinea. The Burmese materials were from three northern provenances (Myitkyina, west Katha and Mongmit) and six southern provenances (Pyinmana, South Toungoo, Thayetmyo, Zigon, Tharawaddy and Kawkareik).

After six years, survival varied significantly between the provenances. At each test site local materials showed higher survival percentage than those from distant sources.

Height growth was not statistically analysed but there were some indications of differences between provenances and of provenance x test site interaction. Additional details are not available.

2.4.3 Tanzania

In 1965 replicated trials of 11 provenances were established at Kihuhwi-Sigi Forest Reserve in Tanga Region (5^{o} 08'S Lat., 30^{o}41'E Long., 180 m a.s.l. Alt.). The trials included seed lots from India, Indonesia, South Vietnam, Sudan, Nigeria, New Guinea and from local stands. Studies were made of height growth, basal area, diameter growth, height to the base of the first living branches, straightness, fluting, forking, flowering habit and survival. The most recent account of the trials was the fifth-year report prepared by Persson (1971b)

There were very highly significant provenance differences for height growth, straightness and fluting. Plants from

Indonesia gave the best height growth whilst those from central India showed the poorest results. The local materials gave the best straightness while those from central India were the most crooked. The plants from central India showed the least fluting and the Indonesian provenances the most, followed by the Keravat (New Guinea) and Kihuhwi (local) provenances.

Although statistical analysis was not done, variations in survival and flowering were exhibited between the provenances. Local provenance from Kihuhwi had the highest survival while the Keravat provenance showed the poorest results. Late flowering was found mostly in the local material from Mtibwa and from South Coimbatore (India) whilst early flowering was mostly found in the trees from Keravat.

By scoring each provenance from the traits studied, excluding survival and flowering, Persson concluded that although the best provenance was from the exotic plantations in S. Coimbatore, local provenance either Kihuhwi or Mtibwa was among the best. The poorest were the provenances from central India. Seed from local sources was then suggested for teak planting at the test sites.

In a further study in Tanzania, local provenance variation was studied. Progeny obtained by open pollination of 28 mother trees in three plantations in Kihuhwi, Bigwa and in Mtibwa were established at Kihuhwi. Layout was randomized blocks with four replications. Studies were made of various traits as assessed in the 1965-trial. Data measured at age 4 were analysed by Persson (1971a) and are given in Table 2.7 .

Table 2.7 - 4-year results of teak progeny trial at Kihuhwi, Tanzania.

Provenances	Lat.	Alt. (m)	Rainfall (mm)	Height (m)	B.A. (m^2/ha)	Straightness*	Fluting
Kihuhwi	5°12'S	200	1400	12.5	20.06	1.22	1.24
Mtibwa	6°08'S	460	1200	12.4	18.46	1.45	1.12
Bigwa	6°05'S	580	950	11.8	12.25	1.14	1.07

* Higher values indicate more crookedness or fluting

Source: Persson (1971a)

The results showed highly significant differences between progenies in basal area (B.A.) and degree of fluting and significant difference in height growth. The local provenance (Kihuhwi) was best in volume production but worst in fluting. Latitudinal change was small (less than 1°) and possibly of little importance. Rainfall and temperature were stated to be the major causes of the provenance differences.

2.4.4 India

A study of provenance variation of 11 sources from natural range in Burma (2) and in India (9) was laid out in 1931-1935 at seven localities in Madras (2), Madhya Pradesh (2), Uttra Pradesh (2) and in East Bengal (1). However, the only replicated trials were in Madras at Nilambur and South Coimbatore. At the other localities only one plot of each provenance was established.

At Nilambur six provenances were included. The lay-out was a randomized block with four replications. All trees were outplanted in the same year except those from north Burma were planted in the following year. This provenance was badly damaged by monkeys soon after establishment. The trial was thinned at age 9 and 12. Comparative studies were made of diameter and height growth and volume per hectare at age 4, 9 and 15. The results for age 9 and 15 are given in Table 2.8.

At age 9 trees from South Bombay were significantly the best and those from North Burma significantly the poorest in all these characters. At age 15 the materials from North Burma was highly significantly inferior to those other sources in height growth whilst the South Bombay and South Burma sources were significantly superior to all the rest. In diameter growth the provenance from South Bombay was the best while the Anamalias the poorest. With regard to total volume the South Burma material was the best and the North Burma the poorest.

However, Mathauda (1954) considered height growth was the best criterion for comparing the provenances due to some stocking irregularities. Thus the material from South Bombay and South Burma seed sources were considered best adapted to the test sites in Nilambur at 15 y.

The trial at South Coimbatore included four provenances (South Burma, Mount Stuart, Mysore and Nilambur). The layout was randomized block with four replications. Assessments of height and diameter growth and volume production were completed at age 5. Measurements of total volume at age 11 and diameter and total volume at age 15 were discarded due to incomplete data. The results are given in Table 2.9.

Of the five year results the local provenances were superior in height growth and the South Burma provenance inferior to all. With respect to diameter and total volume South Burma provenance was the poorest while the others did not significantly

Table 2.8 - Results of provenance trial carried out in Nilambur.

Provenance	9-year Diameter (cm)	9-year Height (m)	9-year Tot. Vol. (m^3/ha)	15-year Diameter (cm)	15-year Height (m)	15-year Tot. Vol. (m^3/ha)
Nilambur	9.4	11.0	50.0	14.7	15.5	59.1
Anamalais	8.9	10.1	41.3	13.5	14.0	54.3
Travancore	9.4	10.7	50.4	14.5	14.3	56.9
South Bombay	10.4	12.5	61.2	16.8	17.1	76.2
South Burma	9.9	11.6	52.1	16.8	16.5	77.7
North Burma	8.9	9.1	32.9	13.7	13.1	52.1

Source: Mathauda (1954)

Table 2.9 - Results of provenance trial carried out in South Coimbatore.

Provenance	5-year Diameter (cm)	5-year Height (m)	5-year Tot. Vol. (cm^3/ha)	11-year Diameter (cm)	11-year Height (m)	15-year Height (m)
South Burma	6.4	6.1	20.3	11.9	10.1	12.5
Mount Stuart	7.9	7.9	46.7	14.7	13.1	16.2
Mysore	7.4	7.0	33.6	13.7	13.7	15.2
Nilambur	7.4	7.3	34.6	14.0	14.0	15.5

Source: Mathauda (1954)

differ from each other. At age 11 and 15-year measurements, the material from South Burma was the poorest in both height and diameter growth. The remaining did not differ significantly.

Thus the results of the 15-year observation indicated local provenances gave the most promising performances. South Burma material demonstrated the worst results and this was a marked reversal of its performances at Nilambur and also gives further evidence of the existence of provenance x site interaction in the species.

At age 36 wood quality of the four provenances at South Coimbatore was studied by Purkayastha et al. (1972). Assessments were made of wood density (weight/cm length) and rate of growth (rings/inch) from increment cores taken out from 20 randomly selected trees of each provenances (two cores each). Analysis of variance showed significant differences in wood density between the provenances while the rate of growth did not differ significantly. Wood from Mysore and Mount Stuart was significantly heavier than that from South Burma and Nilambur.

2.4.5 Thailand

Provenance trials in Thailand commenced in 1966 and have been entirely directed by the Teak Improvement Centre (TIC). So far 14 replicated trials have been established, eight in the North, three in the Northeast, one in the Central and two in the South (Figure 2.4). Out of the twelve, two trials, one in the North (Kiu Tup Yang, Chiengrai) and one in the Northeast (Klang Dong, Nakhon Ratchasima) were cancelled due to fire damage. Full details of the test sites and establishment procedures are given in Table 2.10.

The present 12 replicated trials include materials from both local and exotic sources.

2.4.5.1 Local Trials (1966-1969)

Local trials included provenances from 63 locations in both natural stands and plantations, covering major parts of the country's natural teak zone (See Section 1.5.3.1, Figure 1.1). Seed was collected in 1965 and in 1968. Full details of 15 provenances of the 1968 collection were given by Hedegart (1971a of Table 1, Figure 1). Materials from the two collections were outplanted in 1966 for the 1965 collection and in 1969 for the 1968 collection. (For full details see Hedegart, 1971a). Test sites for these trials were detailed in Table 2.10 (no 1-6, see also Figure 2.4).

Initial results of the local trials have been reported by Hedegart (1971a, 1974) and are summarized below:

(a) Clear differences in survival (after one year planting) existed between provenances.

(b) Significant differences in height and diameter growth were found between provenances only in the first year but not in the subsequent seven years (Figure 2.5).

(c) No clear differences in site x provenance interaction.

2.4.5.2 International Trials (1972-1974)

Introductory international trials were effected in two test sites in 1972 (see Table 2.10). To provide genetic information under Thailand's climatic conditions international provenance trials have been intensively carried out since 1973 with the co-operation from the Danish/FAO Forest Tree Seed Centre, Denmark. During 1973-74 six trials have been established, three in the North (Chiengmai, Lampang, Lampoon), one each in the Central (Sukhothai), North-East (Khonkaen) and South (Chumporn). Full details of the test sites and establishment procedures were detailed in Table 2.10 and Figure 2.4. These six trials included a range of provenances 8 to 25 from East and West Africa, India, Indonesia, Laos and Thailand (Hedegart, 1974). The trials shared a series of trials including 65 provenances from 11 countries, tested in approximately 50 sites in 14 countries (Keiding, 1973).

No results of the international provenance trials have been reported.

2.5 Provenance Variation under Controlled Environment Conditions

Gyi (1972) has shown variation between seedlings of different provenances in response to day and night temperatures. He conducted experiments under controlled conditions in the CSIRO phytotron, Canberra (Morse and Evans, 1962), using five provenances from Pati (Indonesia), Toungoo (Southern Burma), Kerala State (India), Myitkyina (Northern Burma) and Pakse (Laos). Seedlings of each provenance were grown in three different day and night temperature combinations of 30/22, 30/31, 33/22, 33/31, 36/22 and 36/31^{o}C. Seedlings were harvested two times at 2-week intervals after the start of the treatments. Assessments of variation were made for leaf area, distribution of dry matter growth between plant parts, diameter growth and height growth.

There was clear evidence of provenance variation and of temperature x provenance interaction. Gyi (1972) found Myitkyan

Figure 2.4 - Map showing test sites and the years established of teak provenance trials in Thailand, 1966-1974.

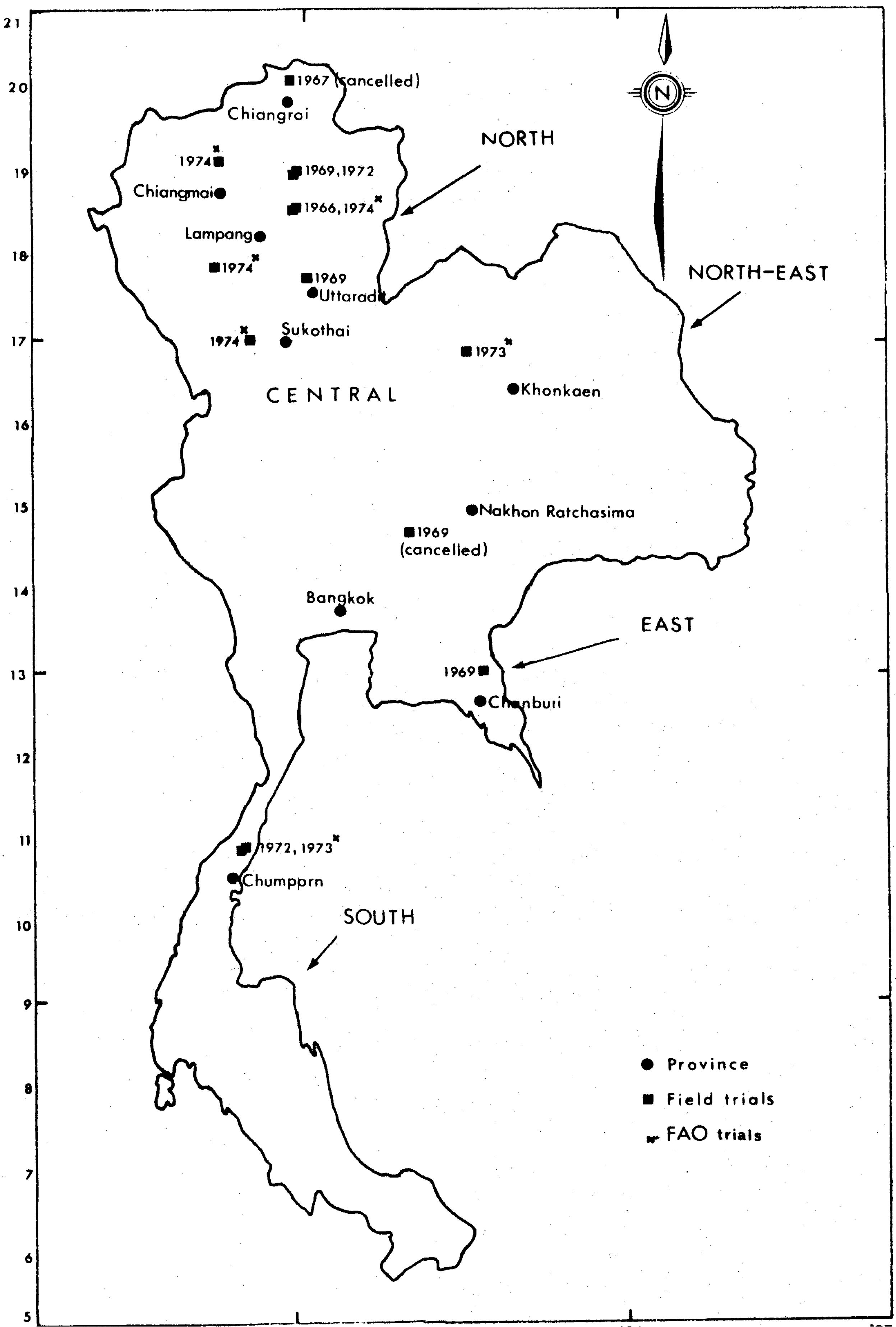


Table 2.10 - Summarized teak provenance trials in Thailand, 1966-1974

Test sites	Established	Lat.	Long.	Alt. (m)	Layout	Prov. present	Plot size	Repli-cation	Spacing (m)
<u>Local Trials</u>									
1. Huey Tak, Lampang	1966	$18^{\circ}40'N$	$99^{\circ}55'E$	320	Randomized block	30	4 x 6	5	2 x 2
2. Kiu Tup Yang,* Chiengrai	1967	$20^{\circ}07'N$	$99^{\circ}54'E$	450	Completely randomized block	30	1	30	2 x 2
3. Doi Tun, Phayao, Chiengrai	1969	$19^{\circ}03'N$	$99^{\circ}59'E$	440	Randomized block	15	6 x 6	6	3 x 3
4. Ban Dan, Uttaradit	1969	$17^{\circ}43'N$	$100^{\circ}07'E$	100	Randomized block	8	6 x 6	6	3 x 3
5. Klang Dong, * Nakhon Ratchasima	1969	$14^{\circ}40'N$	$101^{\circ}15'E$	200	Randomized block	5	6 x 6	6	3 x 3
6. Pong Nam Ron, Chanburi	1969	$13^{\circ}00'N$	$102^{\circ}15'E$	200	Randomized block	10	6 x 6	6	3 x 3

* Cancelled

Table 2.10 (Contd)

Test Sites	Established	Lat.	Long.	Alt. (m)	Layout	Prov. present	Plot size	Repli-cation	Spacing (m)
International trials									
7. Doi, Tun, Phayao, Chiengrai	1972	$19^{o}03'$N	$99^{o}59'$E	200	Randomized block	6	6 x 6	4	4 x 4
8. Tha Sae, Chumporn	1972	$10^{o}35'$N	$99^{o}15'$E	100	Latin square	4	6 x 6	4	4 x 4
9. Pha Nok Khao, Khonkaen	1973	$16^{o}45'$N	$102^{o}oo'$E	300	Randomized block	25	7 x 7	4	4 x 4
10.Pratiew, Chumporn	1974	$10^{o}35'$N	$99^{o}15'$E	100	Randomized block	10	7 x 7	4	3 x 3
11.Huey Som Poi, Ngao, Lampang	1974	$18^{o}40'$N	$99^{o}55'$E	350	Randomized block	8	5 x 5	4	4 x 4
12.Mae Ho Pra, Chiengmai	1974	$19^{o}05'$N	$99^{o}10'$E	600	Randomized block	20	7 x 7	4	4 x 4
13.Mae Lee, Lampoon	1974	$17^{o}55'$N	$98^{o}50'$E	600	Randomized block	9	7 x 7	4	4 x 4
14.Ban Dan Lan Hoi Sukhothai	1974	$17^{o}00'$N	$99^{o}30'$E	120	Randomized block	8	6 x 6	4	4 x 4

Source: Personal contact (K. Pinyopusarerk)

Hedegart (1971a,1974)

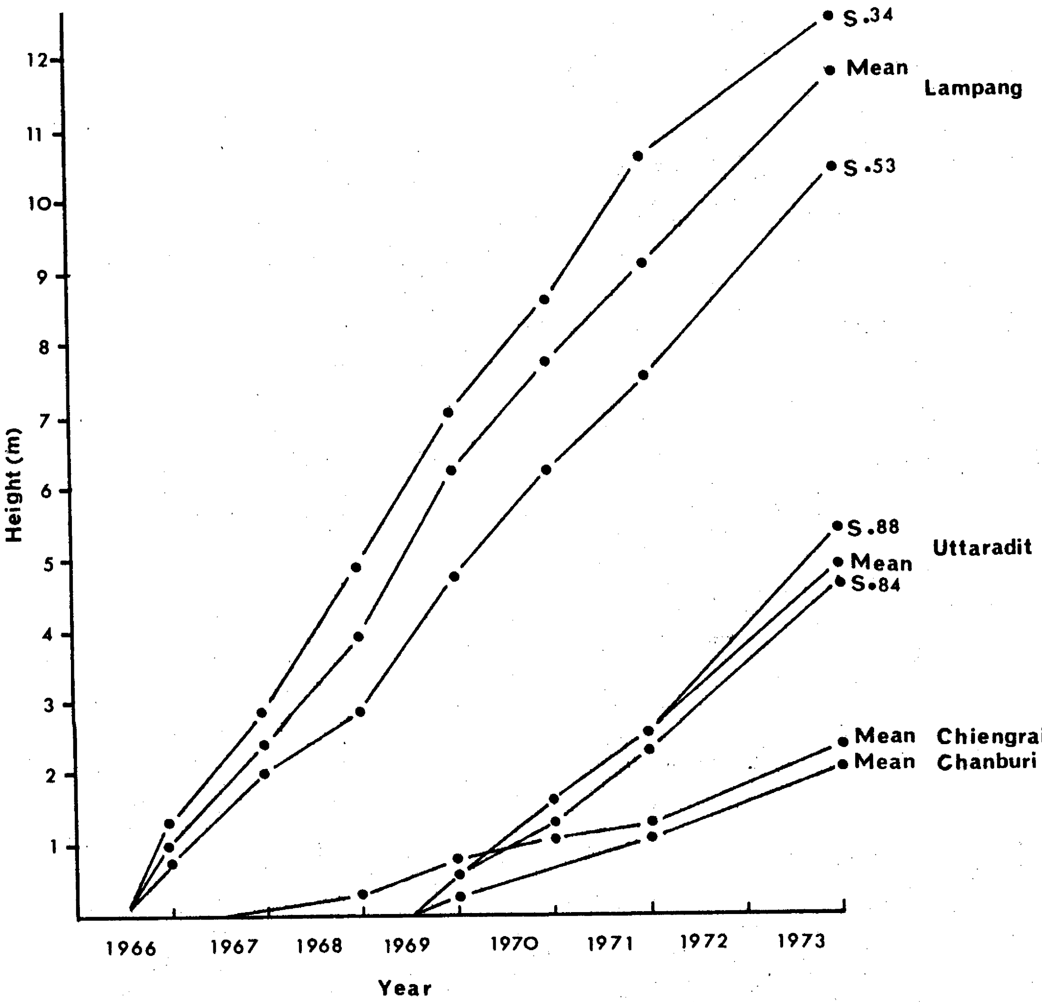


Figure 2.5 - Diagrams showing height development in local teak provenance trials at Lampang, Uttaradit, Chiengrai and Chanburi in Thailand. Height of the best, poorest and/or the mean values for all provenances are shown. S = Teak Improvement Centre seed lot number.

Source: Hedegart (1974)

(Northern Burma) was the best and the Indian provenance the poorest. The Indonesian provenance performed well at 33 and 36 day and 31°C night temperatures whilst Toungoo (Southern Burma) provenance preferred 30 and 33 day and 22°C night temperatures. The Laotian provenance showed very good performance in all these day temperatures and 31°C night temperature, but did not perform as well at 22°C night temperature.

Although the experiment was of short duration, the data obtained were sufficient enough to aid the author in drawing the following interpretations:

(a) The provenance from extreme north of the natural range in Northern Burma (25°N) could tolerate a wide temperature range.

(b) The provenance from more tropical locations appeared to adapt well only to narrow temperature ranges.

2.6 Summary and Discussion

This review indicates clear evidence of individual tree or provenance variation in teak in several morphological characters. Seed characteristics, wood properties, time of onset of flowering, drought and frost tolerance have all been shown to vary.

At provenance trial stage, variation in morphological characters and volume production exists between - and within - localities but no variation pattern has been clarified. Generally, but not exclusively, local seed sources were best adapted. There is some evidence of provenance x site interactions.

Thus although local seed sources may be expected to be optimum in a particular locality, it is essential to establish provenance trials for gaining information to guide a region's planting programme and also to guide further intensive tree improvement programmes.

The only detailed studies of provenance variation available in Thailand are generally still young and the pattern of variation within Thailand is not known. That such variation exists is suggested by the recognition of several morphological races by the timber trades in Thailand.

CHAPTER 3

The Rationale for the Experimental Studies Conducted

3.1 Introduction

The important role of teak in the economy of Thailand has been shown in Chapter 1 with strong emphasis on the need for establishment of teak plantations to maintain the availability of the species.

Tree breeding is an important part of the programmes planned to establish large plantation areas of teak in Thailand. A knowledge of provenance variation is essential for any intensive tree breeding programme.

As noted in the previous chapter there is no detailed knowledge of provenance variation in Thailand. Gyi (1972) suggested in a broad breakdown of teak into provenances over the natural range the Thai material should be treated as one provenance. However, this is clearly inadequate for detailed work in Thailand itself. The existence of provenance variation and provenance x site interaction in the species (Section 2.4 and 2.5) and the recognition by the timber trade of morphological races within Thailand (Section 2.3.2) all indicate the probability of provenance variation in the country. Any early results from provenance studies in Thailand will aid the planning of the tree breeding programmes.

3.2 An Outline of the Experimental Work

Controlled environment facilities exist in Canberra and are suitable for detailed studies of teak seedlings. Gyi (1972) used these for some initial studies of variation in teak. From his studies the existence of variation between five provenances from Burma, Indonesia and Laos has been detected with some evidence of provenance x temperature interaction (for full details see Section 2.5). Gyi's studies thus suggested similar work in teak provenances from Thailand could be used to provide indications of the variation of teak within Thailand in the scope of site (temperature regime) x provenance interaction.

Although comparative testing of Thai and exotic provenances has been carried out in the field in Thailand since 1972 (Hedegart and Yingvanasiri, 1972), no results are available. Similarly no studies of provenance variation between Thai and exotic sources have been reported by other workers. It would therefore be useful to compare Thai and exotic provenance materials under phytotron controlled environments.

Night temperatures exhibit strong control over growth of teak seedlings. Under phytotron conditions, Gyi (1972) found night temperature was more effective in promoting growth of teak seedlings than was day temperature.

Accordingly, the studies were conducted to investigate:

(1) The night temperature requirement of different provenances.

(2) Day/night temperature requirement of different provenances.

(3) Interaction of night temperature x daylength on different provenances.

(4) Provenance variation under temperature regimes which approximately correspond to seasonal temperature regimes of Northern Thailand.

(5) Provenance variation in photosynthesis and respiration rates.

In addition a growth analysis study of teak conducted by Gyi (1972) suggested leaf production was an important determinant of growth rates. This was confirmed by the results of the studies of photosynthesis and respiration reported in this thesis (Chapter 11). No previous comparative studies of leaf development of teak provenances have been reported. A study was therefore included comparing leaf development of different provenances under different temperatures and daylengths.

The studies will be reported in detail in the following chapters:

Chapter 6 - The effects of the temperatures and daylengths tested on height growth, diameter growth, total dry weight, relative growth rate, net assimilation rate and leaf area ratio of teak seedlings.

Chapter 7 - The effects of the temperatures and daylength tested on distribution of dry matter growth of teak seedlings.

Chapter 8 - The effects of the temperatures and daylengths tested on leaf characteristics of teak seedlings.

Chapter 9 - Growth responses of three provenances of teak to temperatures which approximately corresponded to the seasonal temperatures of Northern Thailand.

Chapter 10 - Provenance differences in teak in relation to temperature and daylength effects in terms of overall growth, growth analysis parameters, distribution of dry matter and leaf characteristics.

Chapter 11 - Photosynthesis and respiration in four provenances of teak.

The material, facilities and experimental procedures used will be detailed in chapters 4 and 5 except the procedures used in the study of photosynthesis and respiration which are detailed in Chapter 11.

CHAPTER 4

Description of Experimental Materials and Procedures Used

4.1 Introduction

Four experiments were conducted to determine the effects of temperature and daylength on provenance variation (a) within Thailand and (b) between Thailand and India. The materials and methods used are detailed in this chapter.

Two introductory experiments were also conducted but these have not been reported here. However, for simiplicity in record keeping the original numbering has been retained. Thus the experiments referred to in this thesis are numbered 3, 4, 5 and 6. Experiments 1 and 2 are those not reported.

4.2 Materials Used

The experiments included a total of five Thai provenances and two Indian ones. The original source of the seed used to represent each provenance is indicated below with the code used to simplify identification later in this thesis. The Thai provenances came from:

(1) Chiengrai Province (CR), Northern Thailand.

(2) Mae Gah Seed Orchard (SO), Northern Thailand.

(3) Teak Improvement Centre Seed Source Area No 1 (SSA), Northern Thailand.

(4) Sukhothai province (SK), Central Thailand.

(5) Tak Province (TK), Central Thailand.

The Indian provenances came from:

(1) Masale Valley (MV), Mysore, India.

(2) Sungam Kerala (K), India.

Full details of location and collection are given in Table 4.1.

4.3 Experiments Conducted

Details of materials used and the treatments applied for each experiment are given below. These are summarized in Table 4.2.

4.3.1 Experiments Comparing the Response of Thai Provenances to Temperature and Daylength

One experiment was conducted to determine provenance response to night temperature (experiment 3) and one was conducted to determine provenance response to both night temperature and daylength (experiment 4). All five Thai provenances were used in the night temperature experiment and two (CR and SK) in the night temperature x daylength experiment.

Three night temperatures of 19, 22 and 26^{O}C were used in conjunction with a single day temperature (30^{O}C) in experiment 3 and combinations of these night temperatures with three daylengths (9.5, 11 and 14 h) were used in experiment 4. The single day temperature for this experiment was also 30^{O}C. The regimes used thus gave a wide range from low (19^{O}) to warm (26^{O}) night temperatures and from short (9.5 h) to long (14 h) daylengths by tropical standard.

Both experiments were carried out under phytotron conditions and in naturally lit cabinets (Type C) (see Section 5.2.2). Growing conditions and routine treatments are described in Chapter 5.

Table 4.1 - Details of the provenances of teak used in study.

Provenance	Origin	Lat. (N)	Long. (E)	Alt(m)	Rainfall (mm)	Establishment
	<u>India</u>					
Masale Valley (MV)	Kakanakote Range, Mysore	11°55'	76°10'	823	1270	Nat.
Sungam Kerala (K)	Kerala	8°00'	72°30'	700	2540*	Plant.
	<u>Thailand</u>					
Chiengrai (CR)	Chiengrai Prov., N. Thailand	19°55'	99°51'	450	1715	Nat.
Mae Gah Seed Orchard (SO)	Chiengrai Prov., N. Thailand	19°00'	99°55'	500	1200**	Seed Orchard
TIC Seed Source Area No.1 (SSA)	Lampang Prov., N. Thailand	18°20'	99°55'	350	1400*	Seed Prod. Area
Sukhothai (SK)	Sukhothai Prov., Cent. Thailand	17°20'	99°45'	100	1250***	Plant.
Tak (TK)	Tak Prov., Cent. Thailand	16°40'	99°15'	100	1048***	Nat.

* Unpublished data, Teak Improvement Centre (TIC), Lampang Thailand.

** At Ban Doi Tun , approx. 8 kms east of the origin. Unpublished data, TIC, Lampang, Thailand.

*** Chankao et al. (1972).

Table 4.2 - Summary of teak experiments conducted under phytotron controlled environments.

Experiments	Treatments	Provenances used							Growth rooms used	Seedling age at commencement (days)	Growth period (days)	No. of seedlings used per treatment						
		CR	MV	K	SK	SO	SSA	TK				CR	MV	K	SK	SO	SSA	TK
3. Provenance and night temperature interaction with five Thai provenances.	Three treatments - day temperature $30^{o}C$ x night temperatures 19, 22 and $26^{o}C$.	✓	-	-	✓	✓	✓	✓	C-cabinets	30	53	5	-	-	5	3	4	5
4. Provenance, night temperature and daylength interaction in two Thai provenances.	Nine combinations - day temperature $30^{o}C$ x three daylengths 9.5, 11 and 14h x three night temperatures 19, 22 and $26^{o}C$.	✓	-	-	✓	-	-	-	C-cabinets	30	53	5	-	-	5	-	-	-
5. Provenance and temperature interaction between Thai and Indian provenances.	Four treatments - day/night temperature regimes 24/19, 30/25, 33/28 and $36/31^{o}C$.	✓	✓	✓	✓	-	-	-	Glass-houses	46	85	7	7	7	7	-	-	-
6. Comparisons of provenance performance under conditions approximately to the seasons of Northern Thailand.	Three treatments - day/night temperature regimes 30/13 (winter), 33/25 (rainy season) and 36/19 (summer).	✓	✓	✓	-	-	-	-	Glass-houses	49	91	7	6	5	-	-	-	-

4.3.2 Experiments to Compare the Response of Thai Provenance Material to Indian Material Under Different Temperature Conditions

One experiment was conducted to determine provenance response to a wide range of temperature regimes (experiment 5) and one was conducted to determine provenance response to temperature regimes approximately corresponding to seasonal temperatures in Northern Thailand (experiment 6). Four provvenances, two from Thailand (CR and SK) and the two from India were used in experiment 5 and three of these, one from Thailand (CR) and the two from India were used in experiment 6.

The temperature regimes of 24/19, (day/night) 30/25, 33/28 and 36/31°C were used in experiment 5; three of 30/13, 33/25 and 36/19°C in experiment 6. The latter group of regimes covered approximate seasonal temperature regimes of winter (30/13), rainy season (33/25) and summer (36/19) in Northern Thailand, based on climatic data for Lampang Province (Appendix 2).

The experiments were conducted in the naturally lit glasshouses of the phytotron (See Section 5.2.4) under growing conditions and routine treatments as detailed in Chapter 5.

4.3.2.1 An Experiment to Compare Responses of Net Photosynthesis and Dark Respiration Rates of Thai Provenances to Indian Provenances

This study was conducted as part of experiment 5 to determine provenance variation in net photosynthesis and dark respiration rates between Thai and Indian provenances under four temperature regimes. The provenances used were the four in experiment 5. The day temperature regimes compared were 24, 30, 33 and 36°C.

For measurements of photosynthesis and respiration rates the seedlings were moved from the glasshouses to an artificially lit cabinet (see Section 5.2.3).

CHAPTER 5

Introduction to Teak Experiments in CERES Phytotron Controlled Environments

5.1 Introduction

The experiments reported in this thesis were conducted at the CSIRO CERES phytotron in Canberra. This chapter outlines the facilities used and general experimental procedures.

5.2 Facilities

Phytotron facilities used included (a) open glass-houses, (b) naturally lit cabinets (Type C) and (c) artifically lit cabinets (Type LB).

Detailed descriptions of these facilities have been given by Morse and Evans (1962).

5.2.1 Open Glasshouses

There are a series of open glasshouses with day temperature ranges between 15 to 36^{o}C and night temperature between 10 and 31^{o}C; in steps of 3^{o}C. For a given glasshouse temperatures are held within 1^{o}C of stipulated levels with the day temperature 5^{o}C higher than the night temperature. Day temperatures are held from 8.00 am to 4.00 pm and the night temperature for the remaining 16 hours.

The light source is natural daylight supplemented as necessary to give a photoperiod of 16 hours. The supplementary lighting is provided by low intensity incandescent lighting giving approximately 25 fc at plant height.

Relative humidity is not controlled but is not allowed to fall below 40%.

Open glasshouses were used in the studies of day/night temperature regime (experiments 5 and 6) effects. Details of these experiments were given in Section 4.3.2 and Table 4.2.

5.2.2 Naturally Lit Cabinet (Type C)

Naturally lit cabinets (Type C) are cabinets in which temperature regime and daylength can be monitored as required. Day temperatures are held from 8.00 am to 4.00 pm and the night temperature for the remaining 16 hours. The cabinets receive eight hours of natural daylight and any necessary extension of photoperiod is provided by low intensity incandescent light of approximately 25 fc at plant height. Humidity is not controlled.

Naturally lit cabinets (Type C) were used in the studies of the effects of night temperature (experiment 3) and of interaction of night temperature and daylength (experiment 4) on the growth of teak seedlings. Details of these experiments are given in Section 4.3.2 and Table 4.2.

5.2.3 Artificially Lit Cabinets (Type LB)

Temperature in artificially lit cabinets (Type LB) can be precisely controlled within the range 4 to 45 ^{o}C. The cabinets are illuminated by fluorescent and incandescent lights with radiation ranging from 22.7 cal $cm^{-2}h^{-1}$ (4,000 fc) at the bottom to 28.4 cal $cm^{-2}h^{-1}$ (5,000 fc) at mid-height of the cabinets. Relative humidity can be controlled at values up to 90%.

Measurements of photosynthesis and dark respiration reported in Chapter 11 were conducted in artificially lit cabinets (Type LB).

5.3 General Procedures for conducting Teak Experiments in Phytotron Controlled Environments

5.3.1 Preparation of Seedlings

(a) Seed storage and testing.

Seeds were kept in cotton bags and stored in a cold room (4^{o}C) when not in use.

Germination of teak seed is sporadic. Accordingly, testing of seed viability of a seed lot was conducted to predict the amount of seeds to be sown for obtaining sufficiently uniform seedlings. 100 seeds of medium size were pretreated using the procedure described below and germination percentage determined. Seeds smaller than average size of individual seed lots were not used.

(b) Pretreatments.

The pre-germination treatment was developed from a series of trials.

Procedure:

Seeds were soaked overnight in running tapwater at room temperature to soften the exocarp. Following this treatment, seeds were soaked in running tapwater at room temperature for 24 hours and dried at $33/25^{o}$C day/night temperature for 48 hours. This soak-and-dry process was repeated up to five times over a period totalling 15 days.

(c) Growth media.

During germination and throughout the experiments a 1:1 mixture of perlite and vermiculite was used as growth medium.

(d) Germination.

Pretreated seeds were sown in plastic trays (29 x 36 x 6 cm) and generally allowed to germinate in an open glass-house at $33/25^{o}$C day/night temperature. However, owing to space limitations, the seeds used in experiment 5 and 6 were germinated at 30/25^{o}C day/night temperature. Seeds were watered twice daily at 12.00 am and 4.00 pm and a modified Hoagland nutrient solution applied daily at 8.30 am. Details of the nutrient solution used are given in Appendix 1.

Normally, germination commenced between five and nine days after sowing and was complete approximately four weeks thereafter.

(e) Transplanting.

Seven days after germination all seedlings with two leaf pairs were transplanted to a 7 cm diameter pot. For certain provenances, later transplantings were necessary due to slow and sporadic germination. In all experiments only seedlings that emerged within 14 days of germination commencement were used.

The potted seedlings were retained under 30/25^{o}C day/night temperature until well established (at least three weeks).

For the seven days immediately following transplanting seedlings were watered only once daily with a modified Hoagland solution in the morning. Over-moistening at this stage is a major cause of high seedling mortality after transplanting. Thereafter an additional watering at 4.00 pm was applied.

(f) Grading.

In all experiments seedlings were graded prior to establishment to experimental conditions. For a given provenance the grading procedure was as follows:

(1) Seedlings were arranged, on the basis of height-growth, into a number of groups equal to the number of replicates of each treatment unit.

Within each group the heights of the seedlings were kept as uniform as possible.

(2) Equal number of seedlings of each group were randomly allocated to each treatment unit so variation in seedling size, as determined by height growth, was evenly distributed between experimental treatments.

5.3.2 Routine Procedures Conducted During Experimental Period

In all experiments, the following procedures were routinely conducted during growth period under experimental treatments.

(a) Watering and nutrient regimes.

Seedlings were watered twice daily with tap water at 12.00 am and 4.00 pm and modified Hoagland solution (detailed in Appendix 1) was applied daily at 8.30 am. To further avoid the soil medium drying out the seedlings were held in saucers containing water to a depth of 1.5 - 2.00 cm.

(b) Repotting.

Seedlings were in 7 cm diameter pots for approximately three weeks after experiment establishment. At this stage the seedlings were repotted to 15 cm diameter plastic pots for the remainder of the experiment.

(c) Position effects.

To nullify position effects pot positions were randomized once weekly. In addition, seedlings were carefully spaced to avoid mutual shading.

(d) Red spider control.

Teak seedlings were attacked by red spider (Tetrachus sp.) in most glasshouses. Effective chemical control was possible through frequent sprayings with dichlorvos solution and overnight fumigating with methyl bromide.

Damage to the seedlings was negligible.

(e) Collection of dead leaves.

When seedlings grew older, the lower leaves became senescent and shed before harvesting. Any of these leaves were collected and their dry weights determined for the inclusion in the volume production figures.

5.3.3 Measurement of Growth Parameters

Growth parameters include both primary and derived values.

Primary Values

(a) Stem height.

Stem height was measured to the nearest 1 mm from the cotyledonary node to the highest visible node on the main stem.

(b) Stem diameter.

Stem diameter was measured by vernier caliper at cotyledon level. Two measurements at right angles, were made and the mean calculated. The measurements were made to the nearest 0.01mm.

(c) Dry weight.

Leaves, stem (above cotyledon level) and roots (below cotyledon level) were separately oven-dried at approximately 80^{o}C for at least three days before weighing. The measurement was made to the nearest 0.001 gm.

(d) Leaf area.

Leaf area was measured by an 'Automatic Area Meter' (Type AAM-5, Hayashi Denko Co Ltd., Tokyo). For convenience, the petiole was morphologically regarded as part of leaf and measured together with leaf lamina. Generally, it was necessary to cut individual leaves for the measurement. The measurement was made to the nearest 0.01 sq. cm.

(e) Leaf dimensions.

In each experiment leaf dimensions (leaf length, leaf width and leaf length:width ratio) were determined from a particular leaf pair of each seedling. As the production of leaf pairs varied between temperature conditions and between provenances used the actual leaf pairs examined varied between experiments. The sixth and fifth pairs above the cotyledon were used in experiments 3 and 4 respectively and the eighth pair in experiments 5 and 6.

Leaf length was taken as the distance from stem to leaf apex including the petiole. The measurement was made to the nearest 0.1 cm. Leaf width was taken at the widest section of the leaf lamina at right angles to the mid rib at about the centre of the leaf. The measurement was made to the nearest 0.1 cm.

Derived Values

(f) Area of individual leaves

The area of individual leaves was estimated using the following equation:

$$\log_e A = 0.2837 + 0.7220 \log_e L + 1.2679\ W$$

where L and W are leaf length and width respectively. Gyi (1972) used a similar procedure and trials not reported in this thesis showed this equation gave a degree of accuracy to $\pm$ 5%.

(g) Growth analysis parameters.

Growth analysis was used in experiments 4 and 6. The concepts and methods of growth analysis have been given in detail by Sestak et al.(1971); Evans (1972) and Ledig (1974). Values for relative growth rate, net assimilation rate and leaf area ratio were calculated using formulae given by Šesták et al. (1971). The symbols used by Ledig (1974) are adopted here.

(1) Relative growth rate (RGR, gm $gm^{-1} day^{-1}$).

Relative growth rate, an index of productivity, is defined as the change in dry weight per unit growing material per unit time:

$$RGR = \frac{\ln W2 - \ln W1}{t2 - t1}$$

where: W1 = total dry weight at the start.

W2 = total dry weight at the end.

t2 - t1 = length of sampling interval.

ln = natural logarithm.

(2) Net assimilation rate (NAR, mg $cm^{-2}day^{-1}$)

Net assimilation rate, are index of physiological activity, is defined as rate of increase of dry weight of the whole plant per unit leaf area per unit time:

$$NAR = \frac{W2 - W1}{LA2 - LA1} \times \frac{\ln LA2 - \ln LA1}{t2 - t1}$$

where: LA1 = leaf area at the start

LA2 = leaf area at the end.

(3) Leaf area ratio (LAR, cm^2 gm^{-1})

Leaf area ratio, an index of leafiness, is defined as the ratio between leaf area to total dry weight:

$$LAR = \frac{LA}{W}$$

Where: W = total plant dry weight.

Values for RGR and NAR reported in experiments 4 and 6 were calculated from primary values (total dry weight and total leaf area) recorded for two consecutive harvests. The time interval was 14 days in experiment 4 and 44 days in experiment 6 (for full details of the experiments see Table 4.2). There were three seedlings of each provenance for each harvest in each treatment in experiment 4 and five, six and seven respectively for provenances MV, K and CR in experiment 6 at each harvest (codes for the provenances were given in Table 4.1). The values for LAR in both experiments were determined from the primary values measured at the final harvest.

(i) Distribution of dry matter (photosynthate)

The allometric growth equation, log (y) = a + k log (x) - where x and y are respective plant dry weights of particular organs (e.g. leaves and roots) - was used to study the distribution of dry matter within plant parts (Ledig and Perry, 1965; Ledig et al., 1970; Gyi, 1972). Working with teak, Gyi obtained similar patterns for his results when using either an allometric equation or logarithmic ratio, $\log_e x/\log_e y$ where x was one plant organ (e.g. leaves dry weight) and y was another (e.g. total plant dry weight). Hence relative distribution of photosynthate between roots, stem, leaves and the whole plant and between shoot and roots, reported in this thesis were determined using logarithmic ratios.

5.4 Statistical Analysis

The parameters in experiments 3, 5 and 6 were tested using standard analysis of variance for a two-factor factorial experiment with unequal frequency(Winer 1971); those in experiment 4 to a three factors factorial experiment with equal observations per cell (Winer, 1971). Values for RGR and NAR in experiments 4 and 6 were calculated for each seedling pair and means per treatment calculated and analysis of variance applied. Treatment differences were analysed at 5% level using least significant difference (LSD) techniques (Steel and Torrie, 1960; Winer, 1971).

CHAPTER 6

The Effects of the Temperatures and Daylengths Tested on Height Growth, Diameter Growth, Total Dry Weight, Relative Growth Rate, Net Assimilation Rate and Leaf Area Ratio of Teak Seedlings

6.1 Introduction

This chapter summarizes the results obtained for height growth, diameter growth and total dry weight in experiments 3, 4 and 5. Although the treatments used in each of these experiments have been detailed in chapter 5, they are summarized here for convenience of reference.

Experiment 3 compared the effect of three different night temperatures of 19, 22 and 26^{o}C in conjunction with a single day temperature (30^{o}C) on five Thai provenances, Chiengrai (CR), Mae Gah Seed Orchard (SO), TIC Seed Source Area No 1 (SSA), Sukhothai (SK) and Tak (TK).

Experiment 4 compared the effects of both daylength and night temperature on two Thai provenances (CR and SK). Daylengths used were 9.5, 11 and 14 h and night temperatures were the same as in experiment 3 (19, 22 and 26^{o}C).

Experiment 5 compared the responses of teak seedlings of four provenances, CR, SK, Kerala (K) and Masale Valley (MV), to four temperature regimes; 24/19, 30/25, 33/28 and 36/31^{o}C.

Growth analysis was carried out on the results from experiment 4 and these results are also included and discussed in this chapter.

6.2 Overall Growth

6.2.1 Height Growth

The results obtained in all three experiments were consistent with optimum height growth being obtained at night temperature regimes between 25 and 28°C. The effect of daylength was less clear, whilst any effect of day temperature in experiment 5 was masked by the night temperature response.

In experiment 3 height growth was clearly and significantly greater the higher the night temperature over the range 19 to 26°C (Table 6.1, 6.2). Pooled figures for all provenances were 26.63 cm at 19°C, 39.04 cm at 22°C and 45.19 cm at 26°C.

The results obtained in experiment 4 produced a highly significant interaction between night temperature (19, 22 and 26°C) and daylength (9.5, 11 and 14 h) (Table 6.3). Despite this interaction, at low night temperature (19°C), height growth was clearly lower than that at other temperatures regardless of daylengths (Table 6.4, Figure 6.1A).

With the results from the two provenances pooled there were some indications of a trend to better height growth at higher night temperatures and at longer days. For example, at higher night temperatures of 22 and 26°C and daylengths of 11 and 14 h the height growth was better the higher the temperature and the longer the day. (Table 6.4, Figure 6.1A).

Analysis of the results obtained in experiment 5 for height gave a highly significant interaction between termperature regime and provenances (Table 6.5). Height growth at the two temperature regimes 30/25 and 33/28°C was similar and optimum in three provenances (CR, SK, K) whilst the other provenance (MV) had a more definite optimum at 33/28^{o}C (Table 6.6, Figure 6.2A). Height growth in all provenances was significantly reduced at 24/19^{o}C and for all provenances except CR at 36/31^{o}C.

6.2.2 Diameter Growth

The optimum temperatures and daylength for diameter growth appeared to vary with provenance. However, there were indications that the optimum night temperature occurred within the range 25 to 28^{o}C.

In experiment 3 there were no significant differences in diameter at the different temperature regimes.

In experiment 4 diameter growth was greater at the night temperatures of 22 and 26 than at 19^{o}C (Table 6.4, Figure 6.1B). The effect of daylength was not clear due to a significant daylength x provenance interaction (Table 6.3). One provenance (SK) showed a significant decline in diameter growth at longer daylength, whilst the other (CR) showed an opposite tendency (Figure 6.1C), but the values for CR did not differ significantly between daylengths.

Diameter growth in experiment 5 was also affected by a significant interaction between temperature regime and provenance (Table 6.5). Clearly, however, diameter growth produced at 24/19^{o}C was markedly poorer than that at other regimes (Table 6.6). At higher temperatures three provenances (CR, SK and K) had greatest diameter growth at 30/25^{o}C and all showed a definite decline in diameter growth at the higher temperature regime of 36/31^{o}C (Table 6.6, Figure 6.2B). In the other provenance (MV) diameter growth peaked at 33/28^{o}C.

6.2.3 Total Dry Weight

In all three experiments there was no interaction between temperature, daylength and provenance in total dry weight production. Night temperature exhibited a strong control with optimum production at approximately 25-28^{o}C, whilst the range of daylengths tested had no significant effect.

In experiment 3 total dry weight was greater the higher the night temperatures but the differences were not significant.

In experiment 4 total dry weight was significantly better at higher night temperatures. The pooled mean values for the two provenances ranged from 10.02 gm at 19^{o}C to 12.65 gm at 26^{o}C (Table 6.4, Figure 6.1D). Dry matter production showed a non-significant trend to be greater at longer daylengths.

In experiment 5 total dry weight was greatest at temperature regime 30/25^{o}C and followed in order of magnitude by values recorded at 33/28, 36/31 and 24/19^{o}C respectively. All differed significantly. The pooled figures for all provenances were 15.13 gm at 24/19, 53.03 gm at 30/25, 46.58 gm at 33/28 and 24.03 gm at 36/31^{o}C. (Table 6.6, Figure 6.2C).

6.3 Growth Analysis

Growth analysis was only effected in experiment 4. The results showed that although relative growth rate (RGR) was generally unchanged over the range of night temperatures and daylengths used, there were definite and contrasting changes in its components, net assimilation rate (NAR) and leaf area ratio (LAR), particularly at different night temperatures. These changes were opposite and in balanace, thereby maintaining RGR at a relatively uniform level.

The values for RGR did not vary significantly at the night temperatures and daylengths used (Table 6.3).

There was a sharp decline in NAR at higher night temperatures. The average values for the two provenances combined decreased significantly from 0.2298 mg cm^{-2} day^{-1} at $19^{o}C$ to 0.1849 mg cm^{-2} day^{-1} at $26^{o}C$ (Table 6.4, Figure 6.3A). The NAR change was independent of daylength over the range used although the highest NAR values were recorded at 14 h.

Leaf area ratio was significantly greater at the higher night temperatures. The average values for the two provenances combined rose from 153.77 cm^2gm^{-1} at $19^{o}C$ to 189.90 cm^2gm^{-1} at $26^{o}C$ (Table 6.4, Figure 6.3B). The LAR was also strongly affected by a significant provenance x daylength interaction (Table 6.3). Although both provenances showed a similar trend of decreased LAR at longer daylengths (Figure 6.3C), the trend was significant in one provenance (CR) but not in the other (SK).

6.4 Summary and Discussion

Please see p. 99.

Table 6.1 - Summarized details of the values from the analysis of variance for growth parameters of teak seedlings in experiment 3, showing degrees of freedom, mean square values and significance levels.

Source of Variation	Prov (P)	N. Temp(T)	P X T	Error
Degrees of Freedom	4	2	8	51
Height growth (cm)	530.21**	1889.60***	73.27	118.27
Diameter growth (mm)	9.46***	5.20	0.73	1.73
Total dry weight (gm)	113.57**	46.97	14.33	26.40

** Significant at 1% level.

*** Significant at 0.1% level.

All other values are not significant at 5% level.

Table 6.2 - Mean height growth, diameter growth and total dry weight figures for teak (Tectona grandis L.f) seedlings of five Thai provenances, grown under different night temperatures for 53 days in experiment 3.

rameters	Provenance (P)	Night Temperature-T (^oC)			Average	LSD (5 %)
		19	22	26		
Height growth (cm)	Northern					
	CR	29.96	37.78	53.60	40.45	4.75 (Single Effect)
	SO	23.93	37.63	40.77	34.11	2.74 (Main Effect - P)
	SSA	33.20	50.90	49.75	44.62	2.12 (Main Effect - T)
	Central					
	SK	26.10	44.04	43.82	37.99	
	TK	19.94	24.88	38.02	27.61	
	Av	26.63	39.04	45.19		
Diameter growth (mm)	Northern					
	CR	8.56	8.50	9.84	8.97	1.82 (Single Effect)
	SO	7.67	8.57	8.93	8.39	1.05 (Main Effect-P)
	SSA	9.38	9.45	10.10	9.61	0.81 (Main Effect-T)
	Central					
	SK	8.36	9.92	9.46	9.25	
	TK	7.02	7.70	7.54	7.42	
	Av	8.20	8.83	9.17		
Total Dry Weight (gm)	Northern					
	CR	9.6474	8.0456	14.2410	10.6447	7.09 (Single Effect)
	SO	6.0990	11.0280	10.4990	9.2087	4.10 (Main Effect-P)
	SSA	12.0740	12.0240	13.2700	12.4560	3.17 (Main Effect-T)
	Central					
	SK	10.6830	15.0840	15.0130	13.5933	
	TK	5.5486	6.3674	5.8889	5.9350	
	Av	8.8104	10.5098	11.7824		

Table 6.3 - Summarized details of the analysis of variance for growth parameters of teak seedling in experiment 4, showing degrees of freedom, mean square values and significance levels.

Parameters	Provenance (P)	Night temp (T)	Daylength (D)	P X T	P X D	T X D	P X T X D	Error
Degrees of freedom	1	2	2	2	2	4	4	72
Overall growth								
Height growth (cm)	149.29	1600.20***	249.26*	16.34	145.88	279.07**	85.25	73.47
Diameter growth (mm)	27.8920***	3.6717*	0.2316	1.3830	4.7217*	0.7780	0.8149	0.9848
Total dry weight (gm)	493.80***	52.20*	12.83	4.98	16.95	10.47	19.63	16.56
Growth analysis parameter								
Relative growth rate (mg mg^{-1} day^{-1})	0.000393	0.000487	0.000041	0.000687	0.000894	0.000208	0.000578	0.000293 (1)
Net assimilation rate mg cm^{-2} day^{-1})	0.00421	0.01000***	0.00324	0.00263	0.00428	0.00064	0.00365	0.00159 (1)
leaf area ratio (cm^2 gm^{-1})	3494.00***	9701.00***	2689.00**	330.50	986.00*	203.10	344.20	292.50

(1) Degrees of freedom = 36

* Significant at 5% level

*** Significant at 0.1% level

All other values are not significant at 5% level.

Table 6.4 - Height growth, diameter growth and total dry weight figures for teak seedlings of two Thai provenances, grown under different night temperatures and daylengths for 53 days in experiment 4. CR = Chiengrai, SK = Sukhothai.

Parameters	Daylength-D(h)	9.5			11			14			Av.	LSD (5%)
	Night temp-T (^{o}C)	19	22	26	19	22	26	19	22	26		
Overall growth												
Height growth (cm)	CR	25.69	36.56	29.38	27.48	33.38	43.70	29.96	37.78	53.60	34.76	3.60(P);4.41(D,T);6.24(PxD,PxT);7.64(DxT)
	SK	31.16	40.52	37.48	31.42	36.00	50.44	26.10	44.04	43.82	37.97	
	Av	28.56	38.54	33.43	29.45	34.69	47.07	28.03	40.91	48.71		
Diameter growth (mm)	CR	7.88	8.12	8.04	8.30	8.66	8.48	8.56	8.50	9.84	8.49	0.42(P);0.51(D,T);0.72(PxD,PxT);0.88(DxT)
	SK	9.64	10.28	9.70	9.20	9.88	10.06	8.36	9.92	9.46	9.60	
	Av	8.76	9.20	8.87	8.70	9.27	9.27	8.46	9.21	9.65		
Total dry Weight (gm)	CR	7.102	9.538	7.577	7.670	8.999	8.595	9.647	8.046	14.241	9.046	1.71(P);2.10(D,T);2.96(PxD,PxT);3.63(TxD)
	SK	13.064	13.391	14.475	11.938	13.943	15.989	10.683	15.084	15.013	13.731	
	Av	10.083	11.465	11.026	9.804	11.471	12.292	10.165	11.565	14.627		
Growth analysis Parameters												
Relative growth Rate (mg mg^{-1}day^{-1})	CR	0.0950	0.0913	0.1032	0.1022	0.0975	0.1029	0.1267	0.0844	0.1249	0.1031	0.0094(P);0.0115(D,T);0.0163(PxT,PxD);0.200(TxD)
	SK	0.1173	0.1008	0.1169	0.1059	0.1207	0.1114	0.0870	0.1094	0.1072	0.1085	
	Av	0.1062	0.0970	0.1101	0.1041	0.1001	0.1072	0.1069	0.0969	0.1161		

Table 6.4 (Cont)

Parameters	Daylength-D(h)	9.5			11			14			Av	LSD(5%)
	Night temp-T (^{o}C)	19	22	26	19	22	26	19	22	26		
Net assimilation rate (mg cm^{-2}day^{-1})	CR	0.1968	0.1746	0.1645	0.2086	0.1755	0.1503	0.2881	0.1770	0.2228	0.1947	0.0211(P);0.0259 (D,T); 0.0366 (PxT,PxD),0.0448 (DxT)
	SK	0.2619	0.1949	0.1974	0.2167	0.2225	0.1862	0.2065	0.2357	0.1872	0.2121	
	Av	0.2294	0.1848	0.1810	0.2127	0.1990	0.1683	0.2473	0.2029	0.2055		
Leaf area ratio (cm^{2} gm^{-1})	CR	179.23	173.36	206.53	162.59	183.00	210.13	143.39	159.95	177.07	177.03	7.19(P);8.81(D,T); 12.45(PxD,PxT); 15.25(DxT)
	SK	151.50	174.36	175.65	148.08	167.51	183.08	137.78	157.89	185.10	164.55	
	Av	165.37	173.86	191.09	155.34	175.26	196.61	140.59	157.92	181.09		

Table 6.5 - Summarized details of the values from the analysis of variance of growth parameters of teak seedlings in experiment 5, showing degrees of freedom, mean square values and significance levels.

Source of Variation	Provenances (P)	Temperature (T)	P X T	Error
Degrees of freedom	3	3	9	96
Height growth (cm)	1219.10***	11315.00***	199.13**	70.32
Diameter Growth (mm)	28.75***	283.34***	4.68*	2.20
Total dry weight (gm)	957.25***	9090.50***	132.93	113.14

* Significant at 5% level

** Significant at 1% level

*** Significant at 0.1% level

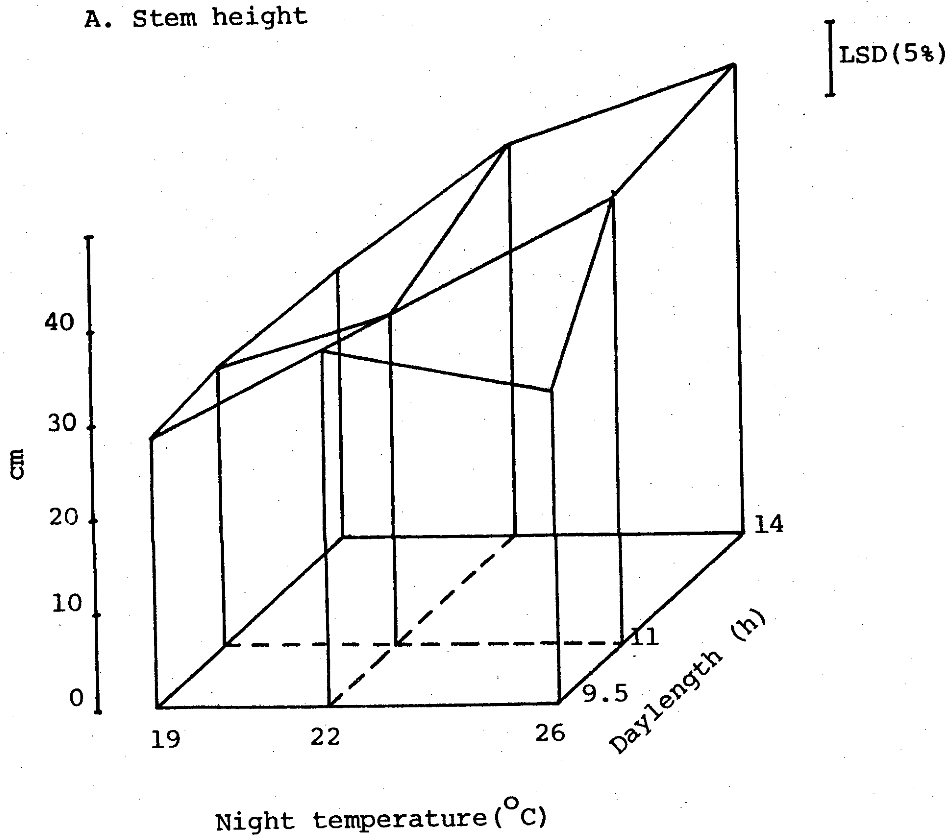
All other values are not significant at 5% level.

Table 6.6 - Mean height growth, diameter growth and total dry weight figures for teak seedlings of four provenances, grown under different temperature regimes for 85 days in experiment 5.

Parameters	Provenance (P)	Temperature (T) (°C)				Average	LSD (5%)
		24/19	30/25	33/28	36/32		
1. Height growth (cm)	Thailand						
	CR	18.11	60.46	64.51	54.39	49.37	
	SK	16.41	55.27	55.90	46.66	43.56	4.44 (P,T) 8.88 (P x T)
	India						
	K	17.63	61.36	62.83	39.11	45.23	
	MV	8.61	41.11	58.51	26.93	33.66	
	Av	15.91	54.55	60.29	41.77		
. Diameter growth (mm)	Thailand						
	CR	8.29	16.70	15.20	12.50	13.17	
	SK	10.33	16.80	14.66	12.61	13.60	0.79 (P,T) 1.57 (P X T)
	India						
	K	8.94	15.54	13.73	12.10	12.58	
	MV	7.97	12.76	13.90	10.46	11.27	
	Av	8.88	15.45	14.37	11.92		
. Total dry weight (gm)	Thailand						
	CR	13.189	57.058	52.510	29.551	38.077	5.641(P,T)
	SK	15.939	54.392	40.747	19.446	32.631	12.282(P X T)
	India						
	K	19.171	61.559	50.469	31.176	40.594	
	MV	12.219	39.118	42.606	15.973	27.497	
	Av	15.130	53.032	46.583	24.028		

Figure 6.1 (For details see page 96)

A. Stem height



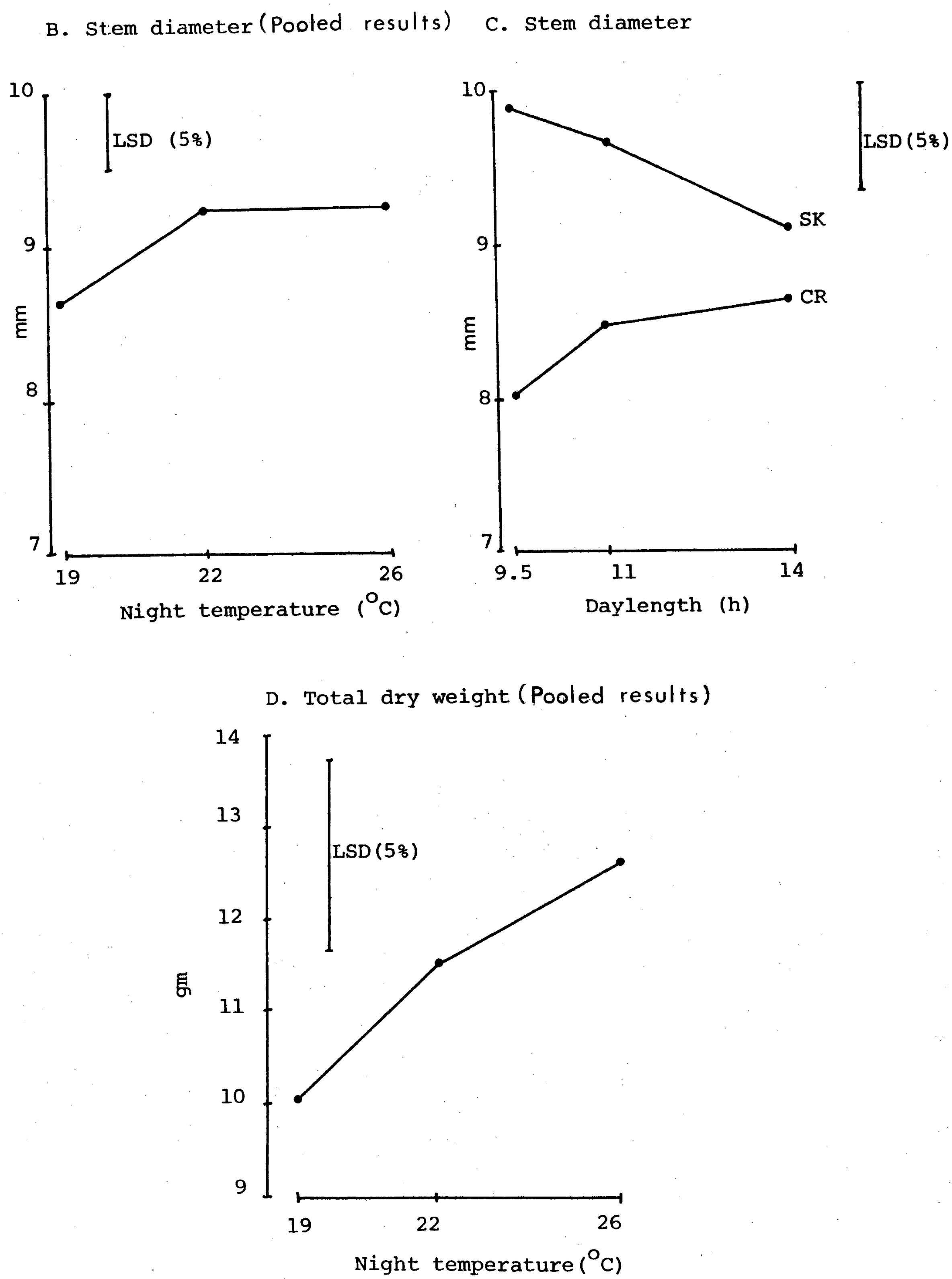
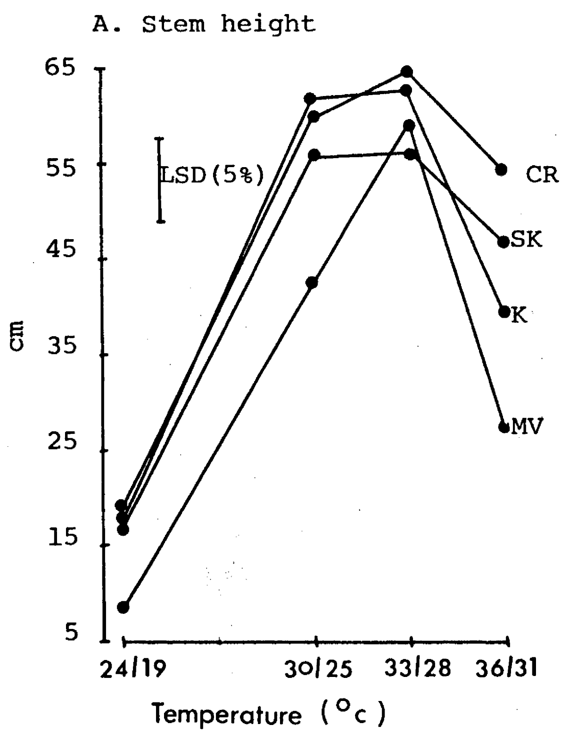
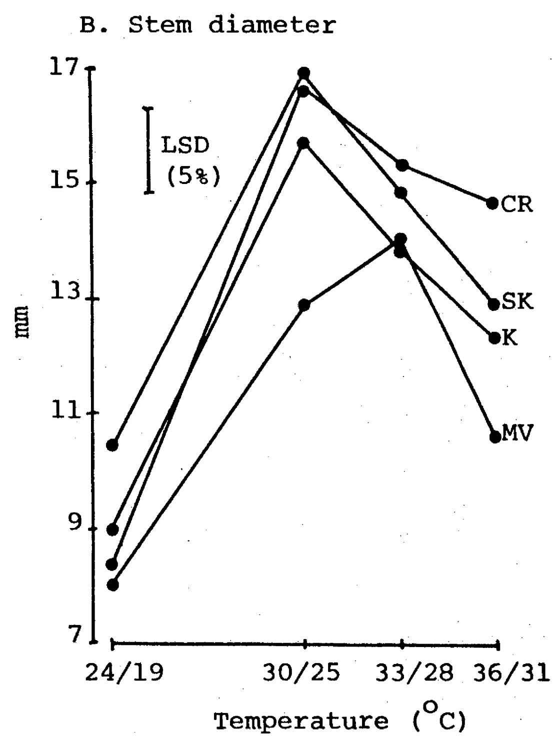


Figure 6.1 - Diagrams showing the effects of night temperature and daylength on stem height (A), stem diameter (B and C) and total dry weight (D) of teak seedlings (after 53 days) of two Thai provenances in experiment 4.
CR = Chiengrai; SK Sukhothai





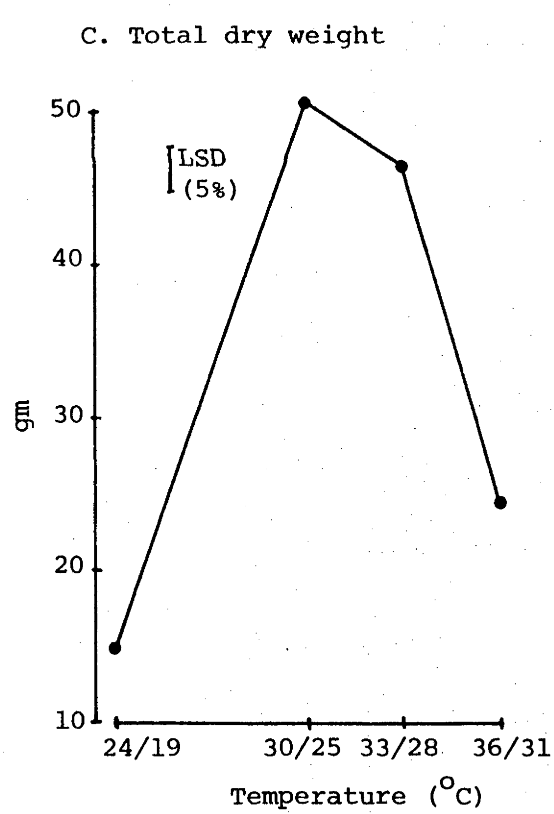


Figure 6.2 - Diagrams showing the effect of temperature regimes on stem height (A), stem diameter (B) and total dry weight (C) of teak seedlings (after 85 days) of four provenances in experiment 5. Codes for the provenances were given in Table 4.1

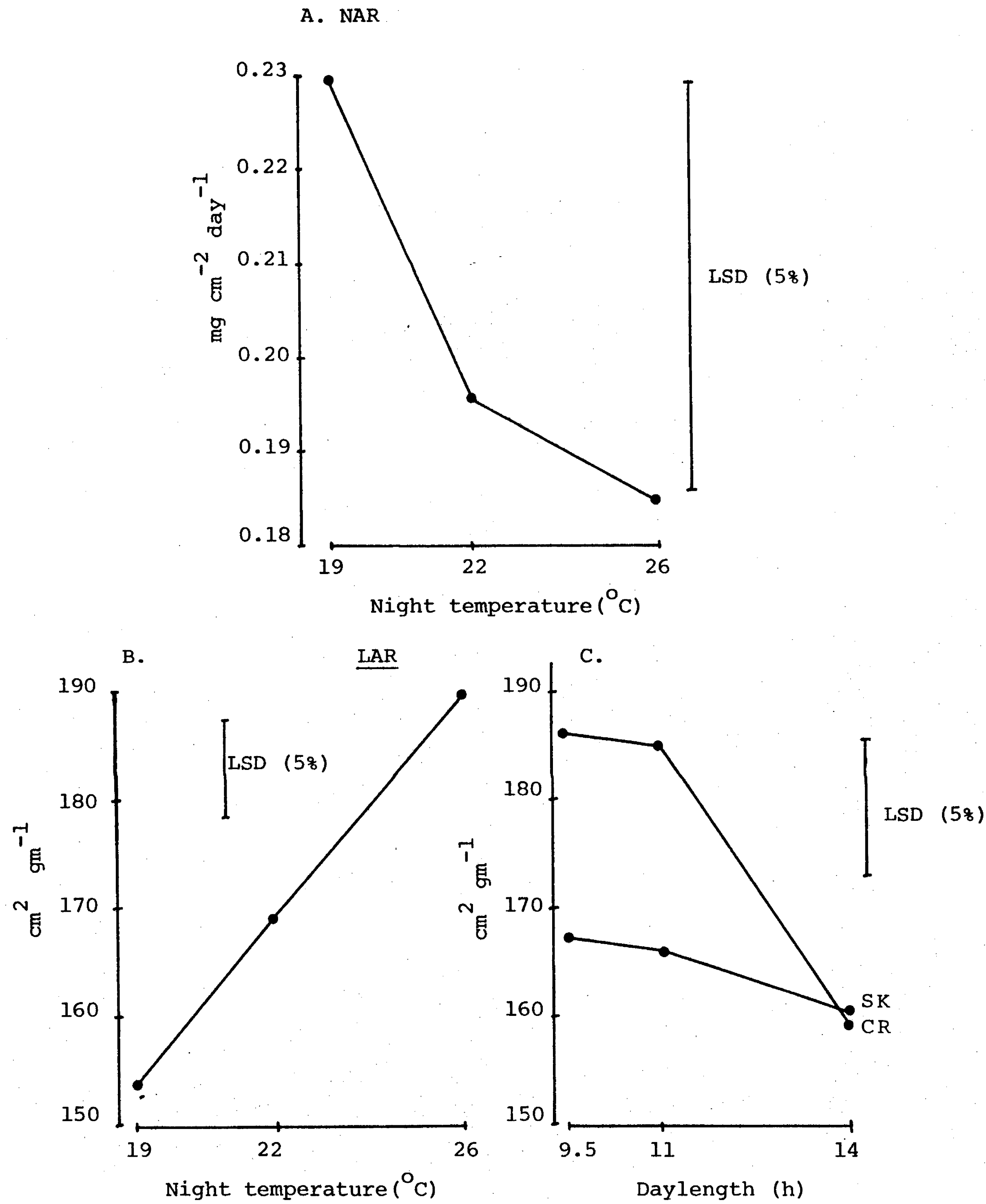


Figure 6.3 - Diagrams showing the effects of night temperature and daylength on NAR (A) and LAR (B and C) of teak seedlings (after 53 days) of two Thai provenances in experiment 4. CR = Chiengrai; SK = Sukhothai

6.4 Summary and Discussion

Effects of three night temperatures (19, 22 and 26^{o}C), three daylengths (9.5, 11 and 14 h) and five temperature regimes (24/19, 30/25, 33/28 and 36/31^{o}C) on growth of teak seedlings were examined under phytotron controlled environments. The seedlings used were from five Thai provenances (three from Northern region and two from Central region) and two from Indian provenances. Growth periods ranged from 53 to 91 days.

6.4.1 Overall Growth

6.4.1.1 Night Temperature

From his intensive studies under controlled environments, Gyi (1972) proposed night temperature was more effective in promoting growth of teak seedlings and this is strongly confirmed by results from this study. Night temperature exhibited strong control over height growth, diameter growth and total dry weight with optimum response over the temperature range 25 to 28^{o}C. However, Gyi (1972) indicated the optimum night temperature for growth was 31^{o}C. In his studies, however, growth was compared at 22^{o} night temperature with 28^{o}C and at 22 and 31^{o}C and there was no direct comparison of 28^{o}C with 31^{o}C. In fact, the effect of night temperature over a range 22 to 31^{o}C was not clearly demonstrated. As results from these recent studies indicate clearly the significant decline in growth with an increase in night temperature from 28 to 31^{o}C the 31^{o} night temperature appears above the optimum for good growth of teak seedlings.

One reason for this is that increased night temperature from 28^{o}C might result in rapid respiration and thus reducing photosynthate accumulation.

It is clear teak seedlings under controlled conditions grow best under night temperature regime of 25 - 28°C. This is warmer than the optima determined under the same conditions for Pinus radiata (24/19° day/night; Cremer, 1968; Rook, 1969; Florence and Malajczuk, 1970), and P. caribaea (27/22°, Slee, Pers. comm.). These are more temperate species and the difference presumably reflects an adaptation to the warm night temperature prevalent in the natural habitat of the species, for example, mean minimum is 20°C in Northern Thailand (Appendix 2). This generally agrees with the results obtained for other tropical tree species by Longman (1972). The species concerned (Cedrela odorata, Triplochiton scleroxylon, Ceiba pentandra, Bombax buonopozense, Gmelina arborea) all established greater shoot growth at night temperatures of 30 or 36 than they did at 26°C. Longman did not however test the intermediate of 28°C.

6.4.1.2 Daylength

Daylength over the range 9.5 to 14 h had relatively little effect on height growth and total dry weight. Similarly, Gyi (1972) reported daylength over the range 8 to 16 h to be a less important control than temperature on the growth of teak seedlings. Although sensitivity of shoot elongation to daylength has been reported in some tropical forest tree species (Njoku, 1964; Longman, 1966, 1972; Awe, 1973) the ambient temperatures in these studies were not controlled. In teak, increase height growth was evident only when long days (11 h and over) were combined with warm night temperatures (22°C and over) (Table 6.4, Figure 6.1A).

6.4.2 Growth Analysis Parameters

6.4.2.1 Night Temperature

RGR was not affected by night temperature over the range 19 to 26^{o}C but the components of RGR exhibited reverse trends. NAR was greater the lower the night temperature whilst LAR was lower. It is also important to note a trend for RGR to be greater at the higher night temperature (28^{o}C).

In his study of the effect of night temperatures (22 and 28^{o}C) and daylength (8, 12 and 16 h) Gyi (1972) reported results for RGR, NAR and LAR similar to the results obtained in this study. It should be noted that a positive relationship between dry weight production and leaf area rather than photosynthetic rate has been reported for several tree species (Matthews, 1963; Newhouse and Madgwick, 1968) and for many agricultural crops (Heath and Gregory, 1938; Nichiporovich, 1956; Watson, 1956). Photosynthetic rate is closely related to NAR (Ledig and Perry, 1969). Newhouse and Madgwick (1968) found a large variation in dry matter production between four hardwood tree species (Poulus balsamifer L., Liriodendron tulipifera L., Ulmus americana L., Acer rubrum L.) which varied considerably in leaf area but not in NAR. Similar findings have been reported for Pinus sylvestris (Gordon and Gatherum, 1968) and P. taeda (Ledig and Perry, 1969). It appears, therefore in teak that over the range of night temperature 19 to 26^{o}C there is a balance between leaf area and net photosynthesis giving only a little change in RGR. However, at higher temperatures (30^{o} or over) it seems probable the decline in photosynthetic rate is not matched by an increase in leaf area and the growth rate declines.

6.4.2.2 Daylength

Daylength did not significantly affect RGR and NAR but LAR was less the longer the daylength. Although differences in NAR were not significant (Table 6.3) in fact, the highest NAR was recorded at 14 h (Table 6.4). Similar effects of daylength of RGR and LAR were reported for teak by Gyi (1972) Gyi also found greater NAR at longer day over the range 8 to 16 h. However, in both cases the increased daylength had no effect on RGR due to opposite change in the components, NAR and LAR.

CHAPTER 7

The Effects of the Temperatures and Daylengths Tested on Distribution of Dry Matter Growth of Teak Seedlings

7.1 Introduction

This chapter summarizes the results obtained for distribution of dry matter growth between roots, stem, leaves, and shoots of teak seedlings in experiments 4 and 5. The treatments and procedures used for each experiment have been described in chapter 5 but the major treatments are summarized here for ease of reference.

Experiment 4 compared the effects of daylength (9.5, 11 and 14 h) and night temperature (19, 22 and 26^{o}C) on two Thai provenances.

Experiment 5 compared the effect of four temperature regimes (24/19, 30/25, 33/28 and 36/31^{o}C) on four provenances, two from Thailand and two from India.

7.2 Distribution of Dry Matter Growth between Roots, Stem and Leaves

7.2.1 Relative Root Growth

There was a definite decline in relative root growth (ln root/ln W) with increasing night temperature in both experiments. In experiment 4 the statistical analysis showed no significant interaction (Table 7.1) and the main effects could therefore be studied separately using pooled provenance values. In this experiment the ln root/ ln W ratio was significantly lower the higher the night temperature (Table 7.2

Figure 7.1A). The same effect was clear in experiment 5 although there was a very highly significant provenance x temperature interaction (Table 7.3). This trend was more definite in the Thai provenance (CR, SK) than the Indian (K, MV) (Table 7.4, Figure 7.2A).

Although daylength affected relative root growth in experiment 4, the pattern was unclear. The ln root/ln W was significantly higher at 14 than at 11 h but at 9.5 h was not significantly different from either 11 or 14 h (Table 7.2, Figure 7.1B).

7.2.2 Relative Stem Growth

Stem growth appeared optimum at night temperature of approximately 25-28^{o}C. In experiment 4 the effect of night temperature on the ln stem/ln W ratio was very highly significant (Table 7.1). Values tended to be higher the night temperature (Table 7.2 Figure 7.1A). There was a significant provenance x temperature interaction in experiment 5 (Table 7.3) but all provenances had peaking values at 30/25 or 33/28^{o}C (Table 7.3, Figure 7.2B).

Relative stem growth in experiment 4 showed a significant tendency to increase with increasing daylength over the range 9.5 to 14 h (Table 7.2 Figure 7.1A).

Relative leaf growth (ln leaf/ln W) was clearly affected by daylength (experiment 4) with a significant decline in a value of the ln leaf/ln W ratio at daylength from 9.5 to 14 h (Table 7.2, Figure 7.1B). The effect of temperature was less clear.

In experiment 4 the ln leaf/ln W ratio was lowest at 22^{o}C night temperature and significantly higher at both 19^{o} and 26^{o}C (Figure 7.1A)

There was a significant provenance x temperature interaction in experiment 5 (Table 7.3). Three provenances (CR, SK andMV) had steadily higher values for ln leaf/ln W ratio at higher temperatures but in the other (K) the effect was less definite with the values at 24/19, 30/25 and 33/28°C not differing significantly (Table 7.4, Figure 7.2C).

7.2.3 Summary

Thus the results obtained in these two experiments indicated definite changes in root, stem and leaf growth at different night temperatures and daylengths. Root growth was greater the lower the night temperatures with the effect of daylength uncertain. Stem growth was clearly controlled by night temperature with optimum production at approximately 25-28°C and was also greater at longer daylengths. Leaf growth declined at longer daylengths but the effect of temperature was unclear due to the provenance x temperature interaction.

7.3 Relative Shoot to Root Dry Weight

Top growth was greater at the higher the night temperature but depressed at longer daylengths provided the night temperature was low (19°C).

In experiment 4 there was a significant interaction between night temperature and daylength in the ln shoot/ln root ratios recorded (Table 7.1). Despite this interaction there was a definite trend for relative shoot : root growth to increase with night temperature at all daylengths (Table 7.2, Figure 7.1C).

The daylength effect was confused. There was a significant trend for the ln shoot/ln root to decrease at longer daylengths under a night temperature of 19^{o}C but no definite trend at 22^{o}C. At 26^{o}C the ratio was significantly higher at 11 h than at both 9.5 and 14 h with non-significant differences between the ratio under the 9.5 and 14 h treatments.

Results obtained in experiment 5 produced a definite and significant trend for the ln shoot/ln root, increasing with increase in temperature regime over the range tested (Table 7.4, Figure 7.2D). Pooled values for all provenances ranged from 1.05 at 24/19^{o} to 1.17 at 36/31^{o}C.

7.4 Summary and Discussion

Please see p. 113.

Table 7.1 - Summarized details of the values from the analysis of variance for distribution of dry matter of teak (Tectona grandis L.f) seedlings in experiment 4, showing degrees of freedom, mean square values and significance levels.

Source of variation	Provenance (P)	Night Temp (T)	Daylength (D)	P X T	P X D	T X D	P X T X D	Error
Degrees of freedom	1	2	2	2	2	4	4	72
$\frac{\ln root}{\ln W}$	0.000473	0.007374***	0.001255*	0.000618	0.000065	0.000056	0.000118	0.000323
$\frac{\ln stem}{\ln W}$	0.000473	0.006866***	0.001953***	0.000061	0.000473	0.000748	0.000378	0.000329
$\frac{\ln leaf}{\ln W}$	0.000702***	0.000183***	0.000534***	0.000031	0.000053	0.000042	0.000046	0.000028
$\frac{\ln shoot}{\ln root}$	0.001556	0.024510***	0.003052*	0.001221	0.000046	0.002502*	0.000755	0.000907

* Significant at 5% level

*** Significant at 0.1% level

Other values are not significant at 5% level.

Table 7.2 - Distribution of dry matter between roots, stem, leaves of teak seedlings of two provenances, grown under different night temperatures and daylengths for 53 days in experiment 4. CR = Chiengrai, SK = Sukhothai.

Parameters	Daylength - D (h)	9.5			11			14				LSD (5%)
	Night temp - T (°C)	19	22	26	19	22	26	19	22	26	Av	
ln root / ln W	CR	0.8207	0.8187	0.8019	0.8283	0.8183	0.7837	0.8368	0.8379	0.7983	0.8161	0.0075(P); 0.0092(D,T); 0.0131 (P X D, P X T); 0.0160 (D X T)
	SK	0.8258	0.8214	0.8168	0.8332	0.8176	0.7933	0.8451	0.8210	0.8124	0.8207	
	Av	0.8233	0.8201	0.8094	0.8308	0.8180	0.7885	0.8410	0.8259	0.8054		
ln stem / ln W	CR	0.8222	0.8435	0.8334	0.8234	0.8424	0.8600	0.8394	0.8525	0.8777	0.8438	0.0076(P); 0.0093(D,T); 0.0132 (P X D, P X T); 0.0162 (D X T)
	SK	0.8295	0.8529	0.8461	0.8313	0.8447	0.8739	0.8289	0.8663	0.8588	0.8480	
	Av	0.8259	0.8482	0.8398	0.8274	0.8436	0.8670	0.8342	0.8594	0.8693		
ln leaf / ln W	CR	0.9394	0.9368	0.9409	0.9383	0.9362	0.0369	0.9322	0.9239	0.9351	0.9355	0.0022(P); 0.0027 (D,T); 0.0038 (P X D, P X T); 0.0047 (D X T)
	SK	0.9477	0.9391	0.9453	0.9417	0.9442	0.9408	0.9352	0.9342	0.9407	0.9407	
	Av	0.9421	0.9380	0.9431	0.9400	0.9402	0.9389	0.9337	0.9291	0.9379		
ln shoot / ln root	CR	1.1867	1.1930	1.2120	1.1777	1.1928	1.2539	1.1618	1.1604	1.2320	1.1967	0.0127(P); 0.0155(D,T); 0.0219 (P X D, P X T); 0.0269 (D X T)
	SK	1.1832	1.1918	1.1999	1.1627	1.1841	1.2399	1.1384	1.1928	1.2073	1.1889	
	Av	1.1850	1.1924	1.2060	1.1702	1.1885	1.2469	1.1501	1.1761	1.2197		

Table 7.3 - Summarized details of the values from the analysis of variance of distribution of dry matter between parts of teak seedlings in experiment 5, showing degrees of freedom, mean square values and significance levels.

Source of variation	Provenance(P)	Temp (T)	P X T	Error
Degrees of freedom	3	3	9	96
$\frac{\ln \text{root}}{\ln \text{W}}$	0.019251***	0.030912***	0.002660***	0.000389
$\frac{\ln \text{stem}}{\ln \text{W}}$	0.01089***	0.04631***	0.00195***	0.00025
$\frac{\ln \text{leaf}}{\ln \text{W}}$	0.00320***	0.00515***	0.00040***	0.00015
$\frac{\ln \text{shoot}}{\ln \text{root}}$	0.05782***	0.08302***	0.00900	0.00497

*** Significant at 0.1% level

Other values are not significant at 5% level.

Table 7.4 - Distribution of dry matter between roots, stem, leaves and shoot figures of teak seedlings in experiment 5, grown under different temperature regimes for 85 days.

Parameters	Provenance (P)	Temperature - T (^{o}C)				Average	LSD(5%)
		24/19	30/25	33/28	36/31		
ln root / ln W	Thailand						
	CR	0.9003	0.8587	0.8516	0.7815	0.8480	0.0289(P X T)
	SK	0.8896	0.8653	0.8096	0.7881	0.8382	0.0104(P,T)
	India						
	K	0.8874	0.8769	0.8767	0.8573	0.8746	
	MV	0.9270	0.9068	0.8867	0.8637	0.8960	
	Av	0.9011	0.8769	0.8227	0.8562		
ln stem / ln W	Thailand						
	CR	0.8119	0.8879	0.8762	0.8692	0.8613	0.0180(P X T)
	SK	0.8053	0.8829	0 8693	0.8501	0.8519	0.0090(P,T)
	India						
	K	0.8076	0.8932	0.8685	0.8563	0.8564	
	MV	0.7349	0.8544	0.8749	0.8071	0.8178	
	Av	0.7899	0.8796	0.8722	0.8457		
ln leaf / ln W	Thailand						
	CR	0.9131	0.9366	0.9419	0.9529	0.9361	0.0130(P X T)
	SK	0.9265	0.9329	0.9534	0.9604	0.9433	0.0065(P,T)
	India						
	K	0.9308	0.9239	0.9300	0.9434	0.9320	
	MV	0.9012	0.9126	0.9159	0.9420	0.9179	
	Av	0.9112	0.9265	0.9353	0.9497		
ln shoot / ln root	Thailand						
	CR	1.0573	1.1403	1.2387	1.2606	1.1742	0.0747(P X T)
	SK	1.0741	1.1276	1.2183	1.1624	1.1456	0.0373(P,T)
	India						
	K	1.0799	1.1154	1.1067	1.1370	1.1098	
	MV	0.9980	1.0700	1.0886	1.1201	1.0692	
	Av	1.0523	1.1133	1.1631	1.1700		

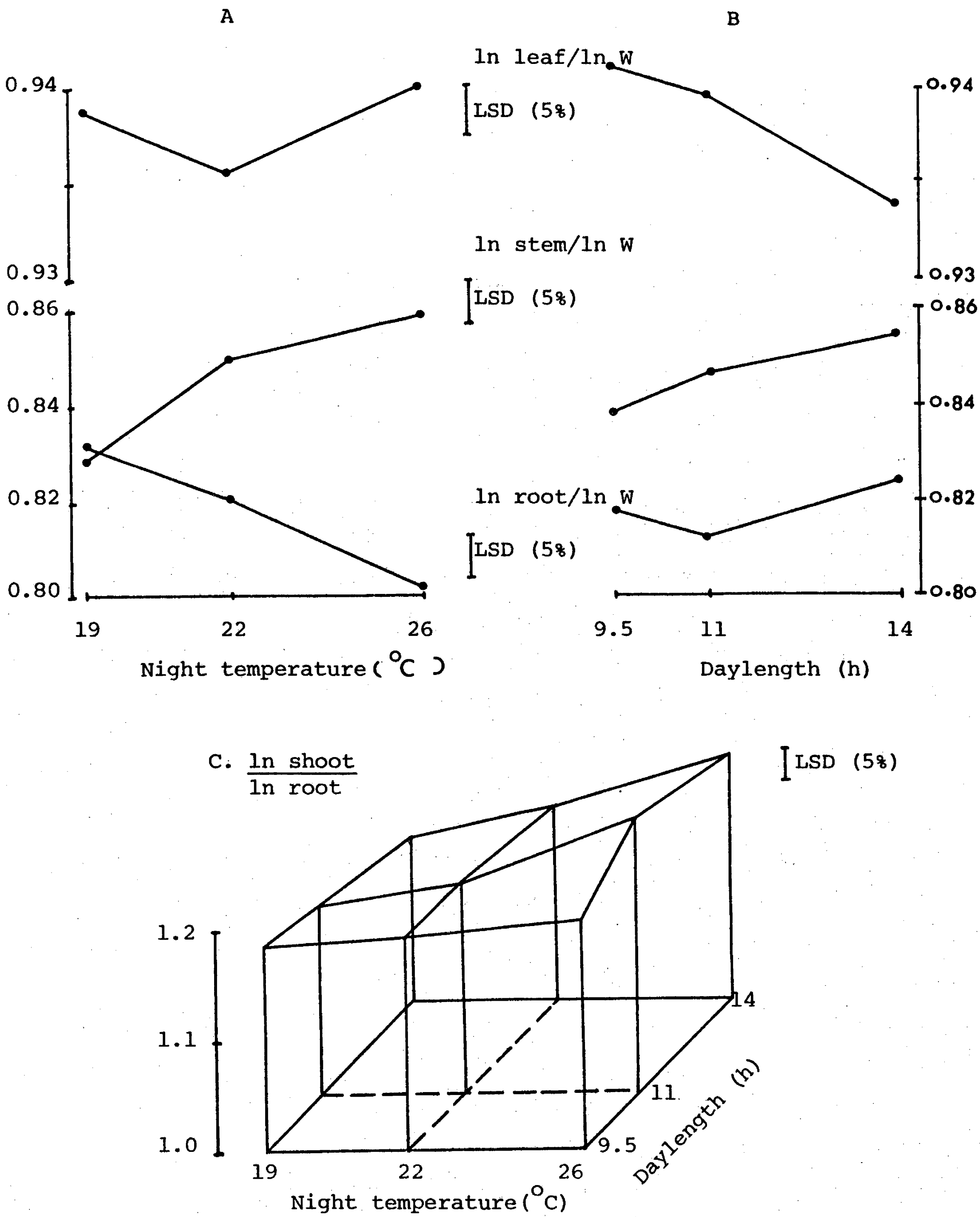


Figure 7.1 - Diagrams showing the effects of night temperature and daylength on distribution of dry matter between various parts of teak seedlings of two Thai provenances (CR and SK)in experiment 4.
A = Effect of night temperature; B = Effect of daylength;
C = Effects of night temperature x daylength.
CR = Chiengrai; SK = Sukhothai

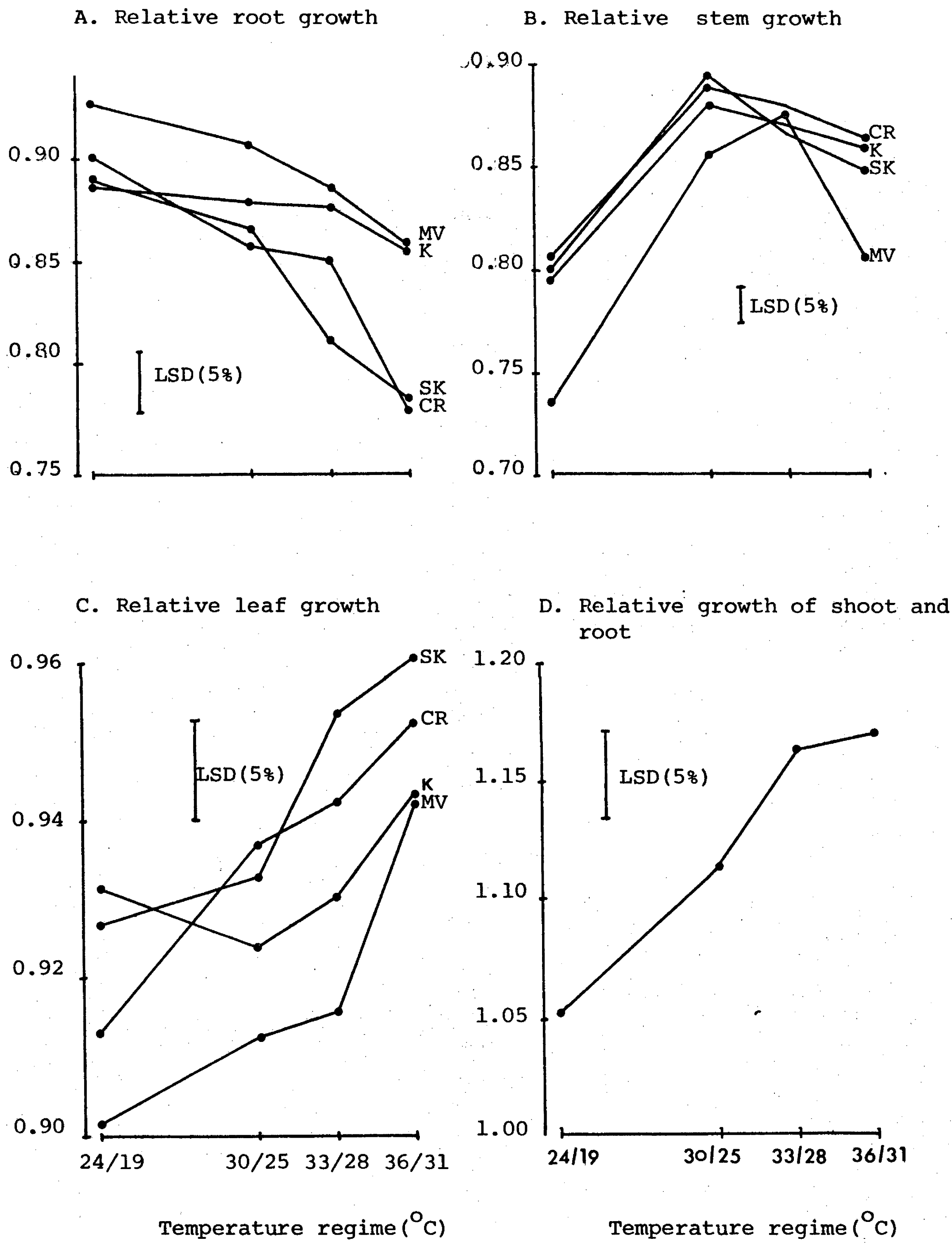


Figure 7.2 - Diagrams showing the effect of temperature regimes on relative root growth (A), relative stem growth (B), relative leaf growth(C), and relative growth of shoot and root of teak seedlings (after 85 days) of two Thai (CR and SK) and two Indian (K and MV) provenances in experiment 5. Codes for the provenances were given in Table

7.4 Summary and Discussion

The effects of night temperature (19,22 and 26^{o}C), daylength (9.5, 11 and 14 h) and temperature regime (24/19, 30/25, 33/28 and 36/31^{o}C) on distribution of photosynthate between roots, stem, leaves and shoot of teak seedlings were examined under phytotron conditions. Seedlings used came from five Thai provenances and two provenances from India. Of Thailand three came from the North and two from the Central.

7.4.1 Distribution of Photosynthate to Roots, Stem and Leaves

Distribution of photosynthate to roots was greater the lower the temperature over the range 19 to 26^{o}C (night temperature) and 24/19 to 36/31^{o}C (day/night temperature). Relative stem growth was controlled strongly by night temperature with an optimum between 25 to 28^{o}C and a decline from 33/28 to 36/31^{o}C. The effect of temperature on relative leaf growth was not clear.

A reverse effect of night temperature on relative root growth was reported by Gyi (1972). He found root growth was greater at 31^{o}C than at 22^{o}C. Gyi also found relative stem growth was greater but relative leaf growth was reduced at 31^{o}C compared to 22^{o}C. However, Gyi did not examine the effects at intermediate night temperatures but he also found important provenance x temperature interaction in photosynthate distribution to the roots. Using five provenances, two from Burma and the others from India, Java and Laos, Gyi found the Indian provenance and one from Southern Burma had greater relative root growth at the low night temperature whilst the other provenance did not. The difference between the two studies may therefore be due to provenance differences and this needs more study.

Relative stem growth was greater the longer the daylength over the range 9.5 to 14 h with relative leaf growth the reverse. The effect of daylength on relative root growth was not clear. Gyi (1972) reported similar results observed over the range 8 to 16 h.

7.4.2 Relative Growth of Shoot to Root

Shoot growth was greater at higher night temperature over the range 19 to 26^{o}C and at the higher day/night temperature regime over the range 24/19 to 36/31^{o}C. Decreased daylength over the range 9.5 to 14 h caused relative shoot:relative root growth to decline. No significant effect of both night temperature over the range 22 to 31^{o}C and daylength over the range 8 to 16 h were found in relative growth of shoot to root of teak seedlings by Gyi (1972). This difference may also be due to provenance differences.

CHAPTER 8

The Effects of the Temperatures and Daylengths Tested on Leaf Characteristics of Teak Seedlings

8.1 Introduction

This chapter summarizes the results obtained from studies of leaf characteristics of particular leaves of teak seedlings in experiments 3, 4 and 5. The leaf parameters measured in all these experiments were:

(1) Total leaf area.

(2) Leaf dimensions (i) Length, width and area of particular leaves.

(3) Leaf dimensions (ii) Length:width ratio of particular leaves.

(4) Leaf growth characteristics - Rate and duration of elongation of particular leaves, number of pairs of leaves present and frequency of production.

Detailed treatments and procedures used in each of these experiments have been given in chapter 4 but they are summarized here for convenience of reference.

Experiment 3 compared the effect of three night temperature regimes (19, 22 and 26^{o}C) in conjunction with a single day temperature (30^{o}C) on five Thai provenances.

Experiment 4 compared the effects of night temperatures of 19, 22 and 26^{o}C and daylengths of 9.5, 11 and 14 h on five Thai provenances.

Experiment 5 compared the effect of four temperature regimes of 24/19, 30/25, 33/28 and 36/31^{o}C on four provenances, two from India and two from Thailand.

To obtain figures for leaf dimensions particular leaf pairs were measured on each tree in each experiment. However, as noted in Chapter 4 different leaf pairs had to be used in the different experiments. The sixth leaf pairs were used in experiment 3, fifth in experiment 4 and eighth in experiment 5.

In experiment 5 rate and duration of growth of particular leaf pairs, number of leaf pairs present and frequency of leaf pairs production were included.

8.2 Total Leaf Area

Total leaf area was strongly controlled by temperature with optimum leaf area production at night temperature between 25 and 28^{o}C. Daylength had no effect.

There was no significant interaction between night temperature and daylength in experiment 3 (Table 8.3). In experiment 4 total leaf area was generally significantly greater the higher the night temperature over the range 19 to 26^{o}C. However, in experiment 3 the differences between 19 and 22^{o}C were not significant. Pooled values for all provenances ranged from 1398.18 sq cm at 19^{o}C to 2192.38 sq cm at 26^{o}C in experiment 3 (Table 8.2) and from 1494.43 sq cm to 2330.60 sq cm in experiment 4 (Table 8.4, Figure 8.1A).

In experiment 5, although there was a very highly significant interaction between provenance and temperature regime (Table 8.5), the results were consistent with a strong night temperature control. All provenances peaked at 33/28^{o}C except one provenance (K) at 30/25^{o}C (Table 8.6, Figure 8.2A).

The different daylength treatments used in experiment 4 gave no clear indication of differences in total leaf area with daylength. Although total leaf area values were higher at 11 and 14 h than at 9.5 h the differences were not significant.

8.3 Leaf Dimensions (i) - Mean Leaf Length, Leaf Width and Leaf Area of the Individual Leaf Pairs Measured in each Experiment

There were no definite changes in the values for leaf length and leaf width at night temperature range 19 to 26°C in experiment 3.

In experiment 4 leaf length increased with increasing night temperature from 19 to 26°C (Figure 8.1B) but the difference between 22 and 26°C was not significant. Leaf width increased from 19 to 22°C and then showed a non-significant decline with further increase to 26°C (Figure 8.1C).

There was no significant effect of daylength on leaf length and leaf width (experiment 4).

In experiment 5 leaf length, leaf width and area of a particular leaf showed very similar response when grown under differing temperature regimes. Analysis of the results obtained produced very highly significant interaction between provenance and temperature regime in all parameters (Table 8.5).

There were differences between the leaf dimensions with temperature regimes. The two Thai provenances (CR, SK) produced leaves which were longer, wider and larger in area at the 30/25 and 33/28°C regimes, than at the other temperatures (24/19, 36/31°C) (Table 8.6, Figures 8.2B, C and D). The differences were usually significant or nearly so. This suggested largest leaf dimensions were produced in the Thai provenances under a temperature regime between 30/25 and 33/28^{o}C.

Similarly, both Indian provenances exhibited differences in leaf dimensions with temperature, but the temperature at which best development occurred was different from those of the Thai provenance. Thus, the Masale Valley material (MV) performed best under the 33/28^{o}C regime and the Kerala material (K) at 30/25^{o}C. Thus one provenance produced largest leaves at a higher temperature than the optimum for the Thai material and one at lower.

8.4 Leaf Dimensions (ii) - Leaf Length:Width Ratio

The leaf length:width ratio or leaf shape was not strongly controlled by night temperature and appeared to vary mostly with provenances. Daylength had no effect on this parameter.

In experiment 3 there was no definite change in leaf length:width ratio over the range of night temperature 19 to 26^{o}C.

In experiment 4 the leaf length:width ratio was affected by a significant interaction between night temperature and provenance (Table 8.3). One provenance (SK) varied little with no significant differences over a range of night temperature between 19 and 26^{o}C, whilst the other provenance (CR) showed a definite trend of higher values at higher night temperatures over the range 22 to 26^{o}C (Table 8.4, Figure 8.1D).

In experiment 5 there was a definite change in leaf length:width ratio with temperature regime with a significant interaction between provenance and temperature regime (Table 8.5). Both Thai provenances (CR, SK) showed a definite and significant decline in the ratio with increasing temperature regime. Thus CR had a value of 2.48 at 24/19 and 1.52 at 36/31, whilst the equivalent values for SK were 2.16 at 24/19 and 1.65 at 36/31^{o}C (Table 8.6, Figure 8.2E). In contrast the Indian material (K, MV) showed a decline with increasing temperature regimes but the effect was much less definite than in the Thai material and was generally not significant with any one provenance (Table 8.6, Figure 8.2E).

8.5 Leaf Growth Characteristics - Rate and Duration of Elongation, the Number of Pairs of Leaves Present and Frequency of Production

Rate of elongation of individual leaves, duration of elongation of individual leaves, number of pairs of leaves at any one time and the time interval between the appearance of successive leaves are all related. All these parameters except the number of pairs of leaves at any one time were affected by significant interaction between provenance and temperature regime (Table 8.5).

Rate of leaf elongation was optimum at temperatures between 30/25 and 33/28^{o}C. Duration of leaf elongation and the time interval between successive leaves were lower at higher temperature. In contrast, the number of pairs of leaves at any one time was greater at higher temperatures.

8.5.1 Rate and Duration of Leaf Elongation

All provenances had peaking values of the rate of leaf elongation at temperature between 30/25 and 33/28^{o}C and values measured for all provenances did not differ at these temperatures. (Table 8.6, Figure 8.2F). In contrast, all provenances showed a definite and significant decline in duration of individual leaf growth with increasing temperature regime (Table 8.6, Figure 8.2G). Thus, in general, at high temperature regime the rate of leaf elongation was rapid but duration of leaf growth was short. At very high temperature of 36/31^{o}C the rate was less rapid and duration of growth remained short.

8.5.2 Number of Leaf Pairs and Frequency of Leaf Pairs Production

Number of pairs of leaves was greater the higher the temperature regime. The mean values for provenances combined ranged from 9.6 pairs of leaves at 24/19 to 14.0 pairs of leaves at 36/31^{o}C (Table 8.6, Figure 8.2H). In contrast, the frequency of leaf pairs production showed a definite trend to decrease with an increase in temperature regime except one provenance (SK) at temperature regimes between 30/25 and 33/28^{o}C (Table 8.6, Figure 8.2I). Thus, the greater number of pairs of leaves at higher temperatures was due to the shorter period required for emergence of a new pair of leaves.

8.6 Summary and Discussion

Please see p. 132.

Table 8.1 - Summarized details of the values from analysis of variance for growth parameters of teak seedlings in experiment 3, showing degrees of freedom, mean square values, and significance levels.

Source of variation	Provenance (P)	Night Temp (T)	P X T	Error
Degrees of freedom	4	2	8	51
Total leaf area (sq cm)	2142700***	3554600***	325150	481780
Leaf length (cm)	62.06	25.63	27.93	27.96
Leaf width (cm)	25.93***	0.99	6.05	5.71
Leaf length-width ratio	0.1507***	0.0558	0.0425	0.0263

*** Significant at 0.1% level.

Other values are not significant at 5% level.

Table 8.2 - Mean total leaf area, length of leaf 6, width of leaf 6, area of leaf 6 and leaf length-width ratio figures of teak (Tectona grandis L.f) seedlings, grown under different night temperatures for 53 days in experiment 3.

Parameters	Provenance (P)	Night Temp - T (^oC)			Av	LSD (5%)
		19	22	26		
Total leaf area (sq cm)	<u>Northern</u>					
	CR	1332.10	1275.50	2467.40	1690.77	958.37 (Single Effect)
	SO	1100.00	1505.50	1779.60	1461.70	553.31 (Main Effect-P)
	SSA	2093.30	1847.30	2565.80	2168.80	428.60 (Main Effect-T)
	<u>Central</u>					
	SK	1446.50	2229.30	2704.40	2126.73	
	TK	1019.00	1218.80	1444.70	1227.50	
	Av	1398.18	1615.28	2192.38		
Leaf length (cm)	<u>Northern</u>					
	CR	24.42	22.04	24.04	23.50	N.S.
	SO	20.40	21.57	20.53	20.83	
	SSA	25.73	26.28	25.73	25.91	
	<u>Central</u>					
	SK	24.16	25.56	25.40	25.04	
	TK	19.52	24.60	17.12	21.39	
	Av	22.85	24.60	22.56		
Leaf width (cm)	<u>Northern</u>					
	CR	10.88	10.44	10.96	10.76	3.30 (Single Effect)
	SO	8.87	8.70	10.20	9.26	1.90 (Main Effect-P)
	SSA	12.18	12.23	11.65	12.02	1.48 (Main Effect-T)
	<u>Central</u>					
	SK	12.24	12.20	13.52	12.65	
	TK	9.42	12.14	7.94	9.83	
	Av	10.72	11.14	10.85		
Leaf length: width ratio	<u>Northern</u>					
	CR	2.19	2.12	2.25	2.19	0.22 (Single Effect)
	SO	2.08	2.41	2.27	2.25	0.13 (Main Effect-P)
	SSA	2.20	2.15	2.12	2.16	0.10 (Main Effect-T)
	<u>Central</u>					
	SK	1.88	2.04	1.97	1.96	
	TK	2.16	2.28	2.06	2.17	
	Av	2.10	2.20	2.13		

Table 8.3 - Summarized details of the analysis of variance for growth parameters of teak seedlings in experiment 4, showing degrees of freedom, mean square values, and significance levels.

Source of Variation	Provenance (P)	Night temp (T)	Daylength (D)	P X T	P X D	T X D	PXTXD	Error
Degrees of freedom	1	2	2	2	2	4	4	54
Total leaf area (sq cm)	9674000***	5246000***	45760	301800	275600	441300	262600	322100 1/
Leaf length (cm)	216.30***	65.34	3.61	0.31	22.81	1.17	7.95	8.60
Leaf width (cm)	94.99	17.08	1.09	2.05	6.22	0.50	1.46	2.43
Leaf length: width ratio	0.57980***	0.08405*	0.00476	0.08936*	0.02231	0.03328	0.00382	0.02078

1/ Degrees of freedom = 72

* Significant at 5% level

*** Significant at 0.1% level

Other values are not significant at 5% level.

Table 8.4 - Total leaf area, length of leaf 5, width of leaf 5, area of leaf 5 and leaf length-width ratio figures for teak seedling of two Thai provenances, grown under different night temperatures in experiment 4. CR = Cheingrai, SK Sukhothai.

Parameters	Daylength - D(h)	9.5			11			14			Av	LSD (5%)
	Night temp - T(^{o}C)	19	22	26	19	22	26	19	22	26		
Total leaf area (sq cm)	CR	1262.90	1635.10	1556.60	1251.90	1634.20	1801.40	1332.10	1280.90	2460.70	1579.98	238.58(P);292.20(D,T);
	SK	1895.10	2287.50	2569.90	1777.50	2323.90	2886.60	1447.10	2229.30	2704.40	2235.70	413.23(P X D, P X T); 506.10(D X T)
	Av	1579.00	1961.30	2063.25	1514.70	1979.05	2344.00	1389.60	1755.10	2584.55		
Leaf length (cm)	CR	14.35	17.55	18.68	15.43	18.60	18.03	17.45	18.38	19.13	17.51	1.23(P);1.51(D,T);
	SK	20.93	21.85	21.40	19.30	22.60	24.10	16.73	20.48	21.40	20.98	2.13(P X D, P X T); 2.62(D X T)
	Av	17.64	19.70	20.04	17.37	20.60	21.07	17.09	19.43	20.27		
Leaf width (cm)	CR	6.05	7.93	7.75	7.10	8.70	7.43	7.88	8.33	8.28	7.72	0.66(P);0.80(D,T);
	SK	9.50	10.85	10.45	8.87	11.10	11.45	7.95	9.60	10.33	10.01	1.14(P X D, P X T): 1.38(D X T)
	Av	7.78	9.39	9.10	7.99	9.90	9.44	7.92	8.97	9.31		
Leaf length: width ratio	CR	2.39	2.22	2.41	2.18	2.15	2.47	2.22	2.21	2.35	2.89	0.07(P);0.09(D,T);
	SK	2.21	2.02	2.05	2.17	2.06	2.14	2.12	2.15	2.08	2.11	0.12(P X D, P X T); 0.14(D X T)
	Av	2.30	2.12	2.23	2.18	2.11	2.31	2.17	2.18	2.22		

Table 8.5 - Summarized details of the analysis of variance of growth parameters of teak seedlings of four provenances, grown under different temperature regimes in experiment 5, showing degrees of freedom, mean square values and significance levels.

Source of variation	Provenance (P)	Temp-T (^{o}C)	P X T	Error
Degrees of freedom	3	3	9	77
1. Total leaf area (sq cm)	25818000***	78116000***	2913100***	777210[1/]
2. leaf length (cm)	914.83***	577.04***	68.14***	11.63
3. leaf width (cm)	283.58***	160.56***	28.67***	5.13
4. leaf area (sq cm)	290520.00***	168890.00***	28340.00***	6020.80
5. leaf length:width ratio	0.1608*	0.9361***	0.1221*	0.0552
6. Rate of leaf elongation (mm/day)	876.69***	1748.50***	47.33*	19.06
7. Duration of leaf growth (days)	51.83***	625.94***	12.72***	3.71
8. Time interval between successive leaves (days)	20.79***	25.82***	5.47*	2.13
9. Number of pairs of leaves	21.25	104.96***	2.08	1.46[1/]

1/ Degrees of freedom=96

* Significant at 5% level

*** Significant at 0.1% level.

Table 8.6 - Figures of 8 characteristics of leaf 8 of teak seedlings of four provenances, grown under different temperature regimes in experiment 5.

Parameters	Provenance (P)	Temperature - T (°C)				Av	LSD (5%)
		24/19	30/25	33/28	36/31		
Total leaf area (sq cm)	Thailand						
	CR	883.10	5393.20	5660.90	4767.70	4176.23	466.99 (P,T)
	SK	1164.00	5324.60	5313.90	4626.40	4107.23	933.98 (P X T)
	India						
	K	1310.80	4702.10	4153.70	2985.40	3288.00	
	MV	745.36	2676.50	3294.80	1740.90	2114.39	
	Av	1025.82	4524.10	4605.83	3530.10		
Leaf length (cm)	Thailand						
	CR	22.57	34.85	34.20	26.17	29.45	
	SK	22.07	38.48	37.15	30.02	31.93	2.02 (P,T) 4.04 (P X T)
	India						
	K	21.80	31.79	25.76	19.32	24.42	
	MV	17.80	17.65	21.97	12.47	17.47	
	Av	21.06	30.69	29.77	22.00		
Leaf width (cm)	Thailand						
	CR	9.08	16.07	16.50	14.53	14.05	
	SK	10.13	19.20	20.30	18.40	17.01	1.34 (P,T) 2.68 (P X T)
	India						
	K	10.85	16.57	13.63	10.70	12.94	
	MV	8.13	8.38	10.65	6.65	8.45	
	Av	9.55	16.06	15.27	12.57		
Leaf Area (sq cm)	Thailand						
	CR	122.22	335.61	340.41	241.87	260.03	
	SK	135.44	472.22	486.65	363.41	364.43	45.92 (P,T) 91.85 (P X T)
	India						
	K	145.28	309.57	222.24	131.21	202.08	
	MV	86.27	88.99	143.08	52.74	92.77	
	Av	122.30	301.60	298.10	197.31		

Table 8.6 (Contd)

Parameters	Provenance (P)	Temperature - T (°C)				Av	LSD(5%)
		24/19	30/25	33/28	36/31		
Leaf length: width ratio	Thailand						
	CR	2.48	2.19	2.07	1.52	0.27	
	SK	2.16	2.02	1.84	1.65	1.92	0.14(P,T) 0.28(P X T)
	India						
	K	2.02	1.93	1.91	1.82	1.92	
	MV	2.18	2.11	2.08	1.90	2.07	
	Av	2.21	2.06	1.96	1.72		
Rate of leaf elongation (mm/day)	Thailand						
	CR	13.73	34.17	33.72	30.25	27.97	
	SK	12.40	37.07	37.37	30.58	29.36	2.58(P,T) 5.16(P X T)
	India						
	K	14.17	32.50	32.00	29.22	26.97	
	MV	7.92	17.00	20.01	18.17	15.78	
	Av	12.06	30.19	30.78	27.06		
Duration of leaf growth (days)	Thailand						
	CR	28.50	20.33	19.33	15.33	20.87	
	SK	25.67	21.00	19.50	13.00	19.79	1.14(P,T) 2.28(P X T)
	India						
	K	27.33	16.83	15.57	12.28	18.00	
	MV	27.00	18.67	15.83	12.83	18.58	
	Av	27.13	19.21	17.56	13.36		
Time interval between successive leaves(days)	Thailand						
	CR	16.83	9.67	8.33	6.83	10.42	
	SK	14.33	9.67	9.83	8.67	10.63	0.86(P,T) 1.73(P X T)
	India						
	K	12.83	8.00	7.17	7.00	8.75	
	MV	14.50	8.83	6.83	5.83	9.00	
	Av	14.62	9.04	8.04	7.08		
Number of pairs of leaves	Thailand						
	CR	9.4	11.6	13.0	13.6	11.9	0.6(P,T)
	SK	9.3	11.3	11.7	12.9	11.3	1.3(P X T)
	India						
	K	10.1	13.1	13.6	14.6	12.9	
	MV	9.4	13.6	14.7	15.0	13.2	
	Av	9.6	12.4	13.3	14.0		

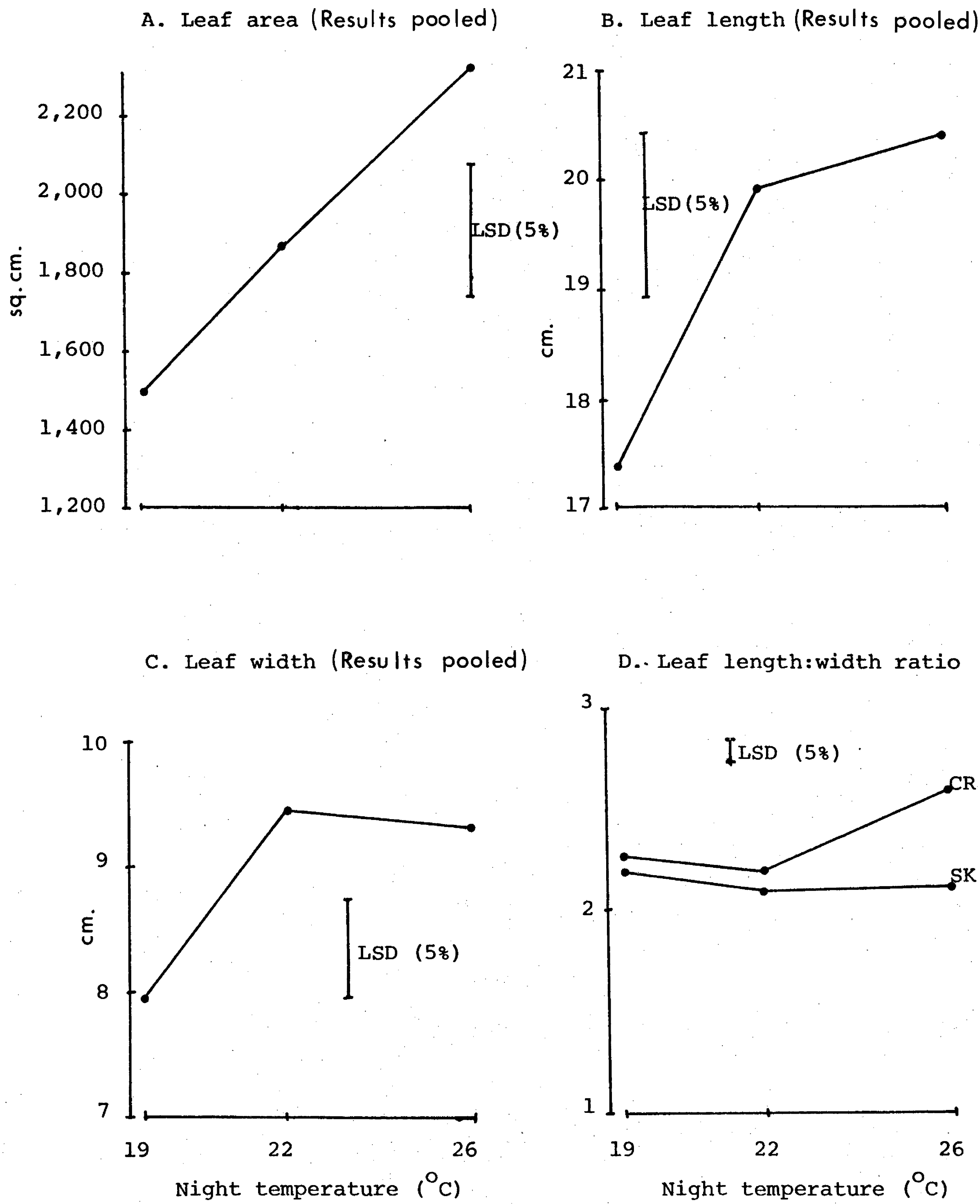


Figure 8.1 - Diagrams showing the effect of night temperature on total leaf area (A), leaf length (B), leaf width (C) and leaf length:width ratio (D) of teak seedlings of two Thai provenances in experiment 4. CR = Chiengrai; SK = Sukhothai.

Figure 8.2 (For details see page 131)

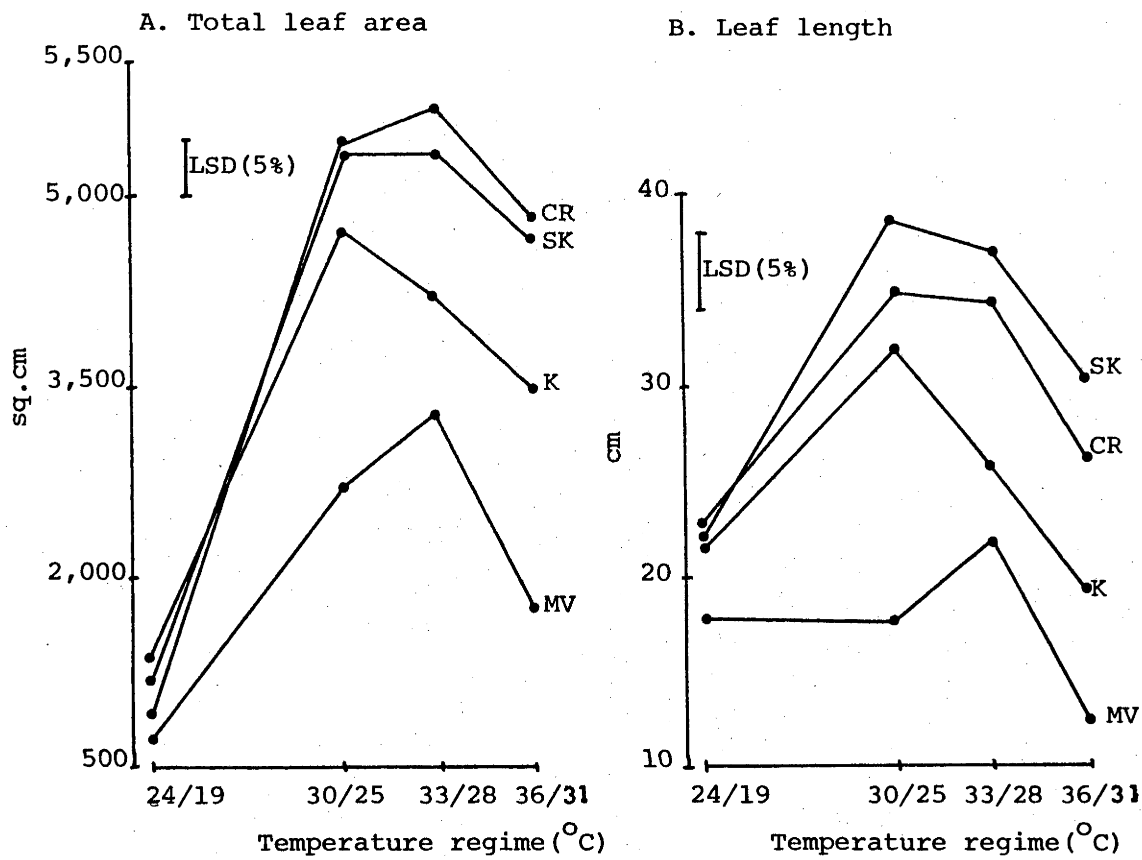
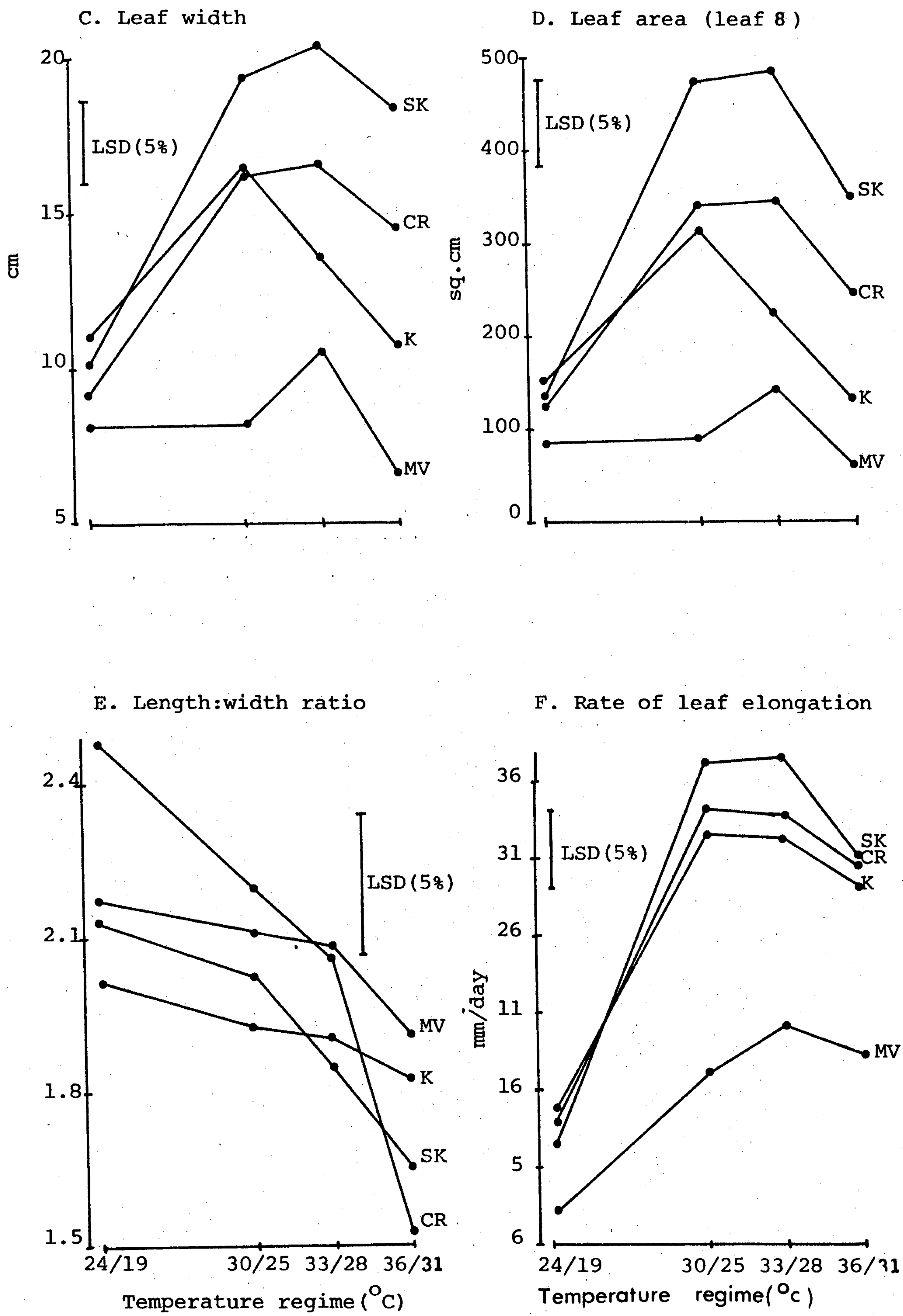


Figure 8.2 (For details see page 131)



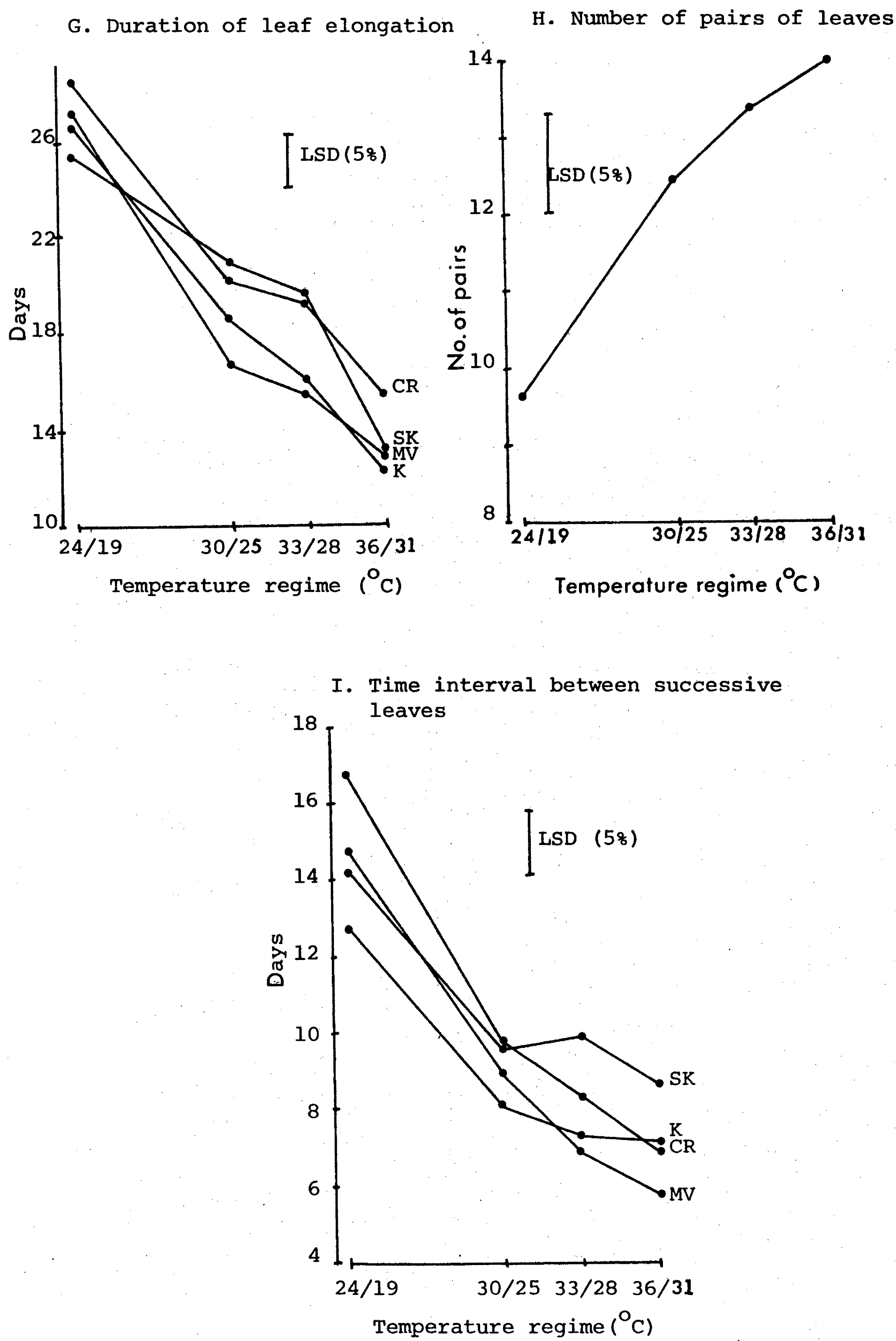


Figure 8.2 - Diagrams showing the effect of temperature regimes on nine characteristics of leaves of teak seedlings of two Thai (CR and SK) and two Indian provenance in experiment 5. Codes for the provenances were given in Table 4.1

8.6 Summary and Discussion

The effects of night temperature (19, 22 and 26°C), daylength (9.5, 11 and 14 h) and day/night temperature regime (24/19, 30/25, 33/28 and 36/31°C) on leaf characteristics of teak seedlings were examined under phytotron conditions. The parameters investigated were as follows:

(1) Total leaf area,

(2) leaf dimensions of particular leaves,

- (a) length,
- (b) width,
- (c) length:width ratio,
- (d) area.

(3) leaf growth of particular leaves,

- (e) rate of elongation,
- (f) duration of elongation,
- (g) number of pairs of leaves produced,
- (h) frequency production.

The seedlings used were from five Thai provenances (three from Northern Thailand and two from Central Thailand) and two from India.

8.6.1 Total Leaf Area

Optimum production of total leaf area occurred at night temperatures between 25 and 28°C. Daylength over the range 9.5 to 14 h had no effect.

8.6.2 Leaf Dimensions

Leaf dimensions were largest at night temperatures between 22 and 26°C and at day/night temperature regimes between 30/25 and 33/28°C. Daylength over the range 9.5 and 14 h had no effect.

8.6.3 Leaf Growth Characteristics

Rate of leaf elongation was optimum at temperature between 30/25 and 33/28°C. Duration of leaf elongation and the time interval between successive leaves were lower the higher the temperature regime. Conversely, numbers of pairs of leaves produced were greater the higher the temperature.

Results of this study indicate the importance of the leaf area as a control of dry matter production. Leaf area production is related to dimensions of individual leaves rather than to the number of leaves produced. Thus the number of leaves produced was greatest at 36/31°C but total leaf area at this regime was much poorer than at 30/25°C (Figure 8.2 and H). This is supported by the existence of an inverse relationship between duration of individual leaf growth and the time interval between successive leaves. Where leaves grew for a longer period the appearance of later leaves was delayed.

Importantly, although not directly comparable, optimum temperatures for leaf area production (25 - 28°C night) appear similar to those for rate of individual leaf growth (30/25 - 33/28°C day/night) and for dry matter production (Chapter 6).

These phytotron studies are intended to aid understanding of seedling behaviour in relation to daylength and temperature. It would be most desirable if these results could be applied as an aid for predicting the performance of seedlings in the field. For this purpose the rate of leaf elongation may be a most important parameter to study. In grass species leaf elongation is more sensitive to temperature than to other environmental factors such as solar radiation and daylength

(Robson, 1969). In teak, the effect of variations in temperature on leaf extension could be detected within one day so the effect of short-term fluctuation in temperature might possibly be determined by field studies of leaf elongation. Other leaf characteristics e.g, width, number of leaves were affected more slowly by temperature so the effect of short-term fluctuation in temperature on these parameters would be hard to investigate. Thus a study of the effect of temperature on elongation of individual leaves may give good indications of the effects on rate of leaf area production and dry matter accumulation.

CHAPTER 9

Growth Responses of Three Provenances of Teak (Tectona grandis L.f) to Temperatures Which Approximately Corresponded to the Seasonal Temperatures of Northern Thailand

9.1 Introduction

This chapter records the results of the experiment (No 6) conducted in an attempt to determine the importance of local Thai seasonal conditions to provenance variation. Three temperature regimes were used and these were based on the seasonal temperatures of Northern Thailand. The responses of two Indian provenances and one Thai provenance were compared under these conditions.

It would have been preferable to include more Thai provenances but of five tried only one germinated satisfactorily.

9.2 Materials and Methods

This experiment was carried out in the CERES Phytotron, Canberra. The facilities used have been described in Section 5.2.

Three provenances, one from Thailand, Chiengrai (CR), and two from India, Kerala (K) and Masale Valley, Mysore (MV) were used. Full details of these provenances were given in Table 4.1.

Following pre-germination treatment Procedure II (Section 5.3.1) seeds were sown on 15/7/75. Germination procedures used were described in Section 5.3.1.

Seedlings were established in an open glasshouse under a 30/25^{o}C temperature regime. On 10/9/75 the seedlings were established following grading in three temperature treatments. There were 36 seedlings/treatment (10, 12 and 14 seedlings of MV, K and CR respectively), making a total of 108 seedlings in the study. The establishment and grading procedures have been detailed in Section 5.3.1.

The three temperature regimes (30/13, 33/25 and 36/19^{o}C) used approximate to the typical seasonal temperature regimes in Northern Thailand, where most of the country's teak occurs. The regimes selected were based on climatic data for Lampang Province (Appendix 2). The three temperature regimes represented the following seasons:

(a) 30/13 for winter (November-February)

(b) 33/25 for rainy season (June-October)

(c) 36/19 for summer (March-May).

Each temperature is the average of the mean monthly maxima and minima for the period specified.

The seedlings were kept on trolleys and moved daily between respective galsshouses at 8.30am and 4.00pm. Half of the seedlings were harvested after 47 days and the remainders at 91 days.

At the first harvest the following growth parameters were measured on individual seedlings:

(a) Oven dry weights of roots, stem and leaves.

(b) Total leaf area.

(c) Length and width of the 8th leaf pairs.

The following growth parameters were determined for individual seedlings at the second harvest:

(a) Oven dry weights of roots, stem and leaves.

(b) Total leaf area.

(c) Stem height.

(d) Stem diameter.

(e) Number of pairs of leaves.

Measurement procedures for these parameters, except the number of pairs of leaves have been detailed in Section 5.3.4.

Growth analysis was conducted using primary values (i.e. total leaf area and total dry weight) recorded for the two consecutive harvests over a 44-day interval. The symbols used and the formulae applied for determining relative growth rate, net assimilation rate and leaf area ratio have been described in Section 5.3.4.

Distribution of dry matter growth between plant parts were based on the values recorded at the second harvest (91 days) using logarithmic ratio. Detailed procedures have been given in Section 5.3.4.

In the studies of leaf characteristics, length, width and area of leaf 8 were the means of the pooled values for two leaves of the 8th pairs. The area was determined using the equation given in Section 5.3.4.

Primary and derived values were subjected to the standard analysis of variance procedures using unequal cell frequencies (Winer, 1971). To determine differences between treatments or provenances the standard least significant difference procedures were used (Steel and Torrie, 1960; Winer, 1971).

9.3 Results

9.3.1 Effect of Temperature

9.3.1.1 Overall Growth (Height Growth, Diameter Growth and Total Dry Weight)

All three parameters were greatest at 33/25°C and followed in order of magnitude by 36/19 and 30/13°C. Differences between temperature treatments were significant except for the values for height growth obtained at 33/25 and at 36/19°C. Values recorded under the 30/13 were very low. The mean of the pooled height growth for the three provenances ranged from 9.65 cm at 30/13 to 44.50 cm at 33/25, diameter growth from 7.04 mm to 12.06 mm and total dry weight from 7.70 gm to 39.00 gm (Table 9.2, Figure 9.1A, B and C). Clearly overall growth was greatest at 33/25 and poorest at 30/13°C.

9.3.1.2 Growth Analysis

Analysis of results obtained produced a significant interaction between provenance and temperature in relative growth rate (RGR) (Table 9.1). Two provenances (CR and MV) had peaking values between 33/25 and 36/19°C whilst the other provenance (K) showed little variation over the temperature regimes tested (Table 9.2, Figure 9.2A). Thus RGR varied with provenance and was likely to be higher at 33/25 and 36/19 than at 30/13°C.

Net assimilation rate (NAR) did not vary with the temperature regimes tested.

Leaf area ratio (LAR) peaked at 36/19 although the values recorded at 33/25 were not significantly lower (Table 9.2, Figure 9.2B). LAR was poorest at 30/13°C and was definitely poorer than that at other regimes.

Thus results obtained from growth analysis showed the temperature regimes (30/13, 33/25 and 36/19°C) had parallel effects on change in RGR and in LAR and both had peaking values at temperatures between 33/25 and 36/19°C. NAR was independent of the temperature regimes imposed.

9.3.1.3 Distribution of Dry Matter

There were definite changes in relative root growth (ln root/lnW) with a significant provenance x temperature interaction (Table 9.1). Relative root growth of two provenances (K and MV) changed little over the temperature used but the other provenance (CR) had a significantly lower ln root/ln W ratio at 30/13 than at 33/25 and at 36/19^{o}C (Table 9.2, Figure 9.3A). Thus response of root growth to temperature regime varied with provenance.

Relative stem growth to total dry weight (ln stem/ ln W) was significantly greater at 33/25 than at 36/19^{o}C, whilst the value at 36/19^{o}C was significantly greater than at 30/13^{o}C (Table 9.2, Figure 9.3B). Clearly optimum temperature for stem growth was 33/25^{o}C.

There was no significant change in relative leaf growth to total dry weight (ln leaf/ln W) over the temperature regimes used, differences being not definite between treatments.

Relative shoot growth to root dry weight (ln shoot/ ln root) was affected by a significant interaction between provenance and temperature (Table 9.1). Two provenances (CR and K) did not vary significantly with temperature used. In the other provenance (MV), the ln shoot/ln root was greater at 36/19 than at 30/13^{o}C but the differences between the values obtained at 30/13 and 33/25 and at 33/25 and 36/19^{o}C were not significant (Table 9.2, Figure 9.3C). Therefore, shoot growth appeared constant over the temperature regimes used except in the Masale Valley (MV) provenance where it was limited at the lower temperature of 30/13^{o}C.

In summary, stem growth was optimum at 33/25^{o}C. No definite change was found in leaf growth over the temperature regimes of 30/13, 33/25 and 36/19^{o}C, whilst relative root growth and the shoot/root responses varied with provenance.

9.3.1.4 Leaf Characteristics

Six parameters of leaf characteristics were studied and were grouped according to their relationship as follows:

(a) Leaf dimensions (i)

(1) Length of leaf 8

(2) Width of leaf 8

(3) Area of leaf 8.

(b) Leaf dimensions (ii)

(4) Length:width ratio.

(c) Leaf growth characteristics

(5) Total leaf area

(6) Number of pairs of leaves.

(a) Leaf Dimensions (i) - Length, Width and Area of Leaf 8.

Analysis of variance of data for leaf length, leaf width and leaf area of leaf 8 gave very highly significant interaction between provenance and temperature (Table 9.1). Despite this interaction all provenances exhibited similar and definite response to temperature imposed. In all provenances the longest and widest leaves and leaves with largest area were produced at temperature of 33/25, followed in order of magnitude by those produced at 36/19 and at 30/13^{o}C (Table 9.2, Figure 9.4A, B and C). Differences were significant between treatments except in the values for leaf width recorded for two provenances at 33/25 and 36/19^{o}C. Thus leaf dimensions were greatest at 33/25 and poorest at 30/13^{o}C.

(b) Leaf Dimensions (ii) - Leaf length:Width Ratio

Leaf length:width ratio was significantly greater at 33/25 than at 30/13 and at 36/19^{o}C, whilst the former was significantly greater than the latter (Table 9.2, Figure 9.4D). Thus the leaf length:width ratio was greatest at 33/25 and smallest at 30/13^{o}C.

(c) Leaf Growth Characteristics - Total Leaf Area and Number of Pairs of Leaves

Total leaf area and number of pairs of leaves were both measured at the final harvest.

Total leaf area peaked at 33/25 followed in order of magnitude by those at 36/19 and at 30/13^{o}C, with significant differences between treatments. Pooled mean values for the three provenances were 466.89, 3110.93 and 1968.57 sq cm at 30/13, 33/25 and 36/19^{o}C respectively (Table 9.2, Figure 9.4E).

Unlike total leaf area number of pairs of leaves was greatest at 36/19 but not significantly greater than that produced at 33/25, where the greatest total leaf area occurred. A temperature of 30/13^{o}C produced poorest leaf growth (Table 9.2, Figure 9.4F).

The results from studies of leaf characteristics showed both leaf dimensions and total leaf area were greatest at 33/25 and poorest at 30/13^{o}C. The latter temperature had also a delayed effect on the emergence of new leaves. Superiority in total leaf area was not related to the number of pairs of leaves present.

9.3.2 Provenance Differences

9.3.2.1 Overall Growth

There were significant differences in height growth between one Indian provenance (MV) and the two other provenances. K showed the greatest height growth although the Thai provenance, CR, was not significantly poorer (Table 9.2). MV produced poorest growth.

Differences in both diameter growth and dry matter production were not significant between the provenances. Although not significant, the values recorded for MV were smallest.

9.3.2.2 Growth Analysis Parameters

Although analysis of variance of data for relative growth rate (RGR) showed significant interaction between provenance and temperature (Table 9.1), there were no differences in RGR at temperatures of 33/25 and 36/19^{o}C. At 30/13, the lowest temperature, K was significantly greater than both CR and MV which did not differ significantly (Table 9.2, Figure 9.2A).

In contrast, there were significant differences in net assimilation rate (NAR), between Thai and Indian provenances. The Thai provenance (CR) was significantly lower than the Indian provenances (K, MV). There was no significant differences in NAR between the Indian materials.

In contrast to NAR, the Thai provenance (CR) showed the greatest leaf area ratio (LAR), significantly greater than the Indian provenances (K, MV). As with NAR there was no provenance variation in LAR between the Indian provenances.

Results from growth analysis gave clear evidence of provenance variation with Thai material having larger leaf area ratio and a lesser net assimilation ratio. Because these effects compensated there were few significant provenance differences in relative growth rate. However, K showed a clear superiority at the lower temperature regime (30/13°C).

9.3.2.3 Distribution of Dry Matter

Although there was a significant interaction between provenance and temperature regime (Table 9.1), the Indian provenances (K and MV) showed greater relative root growth (ln root/ln W) than the Thai provenance at all three temperature regimes used (30/13, 33/25 and 36/19°C)(Table 9.2, Figure 9.3A). However, significant differences were found only at low temperature regime (30/13°C). Thus root growth of the Indian provenances were greater than that of the Thai provenance. The range of variation was greater at low temperature than at higher temperatures.

The Thai provenance, CR, produced greatest relative stem growth (ln stem/ln W) with the values recorded for K not significantly poorer (Table 9.2, Figure 9.6A). MV had significantly poorer ln stem/ln W ratio than the other two provenances.

There were clear differences in relative leaf growth (ln leaf/ln W) between Thai and Indian provenances. The Thai provenance was significantly greater than the Indian provenances which did not differ significantly.

There was also a significant interaction between provenance and temperature regime in shoot growth to root dry weight (ln shoot/ln root) (Table 9.1). Although the ln shoot/ ln root values for the Thai provenance were greater than those for the Indian provenances at all temperature regimes, differences were significant only at the low temperature (30/13°C) (Table 9.2, Figure 9.3C). Thus top growth of the

Thai provenance was greater than the Indian provenances particularly at low temperature.

Clearly, differences in stem and leaf growth existed between Thai and Indian provenances. The Thai provenance was superior to the Indian provenances in both parameters. The differences in root and top growth were greater at low temperatures rather than at higher temperatures.

9.3.2.4 Leaf Characteristics

(a) Leaf dimensions (i) - Length, width and area of leaf 8.

All these parameters were affected by a very highly significant interaction between provenance and temperature regime (Table 9.1). Despite this interaction there were clear differences between Thai and Indian provenances. At 33/25 and 36/19^{o}C the Thai provenance, CR, produced leaves which were longest, widest and largest in area followed in order of magnitude by K and MV with significant differences (Table 9.2, Figure 9.4A, B and C). There were no significant provenance differences in these parameters at low temperature of 30/13^{o}C although the differences did generally parallel those at the higher temperatures. Clearly, therefore the leaf dimensions of the Thai provenance were greater than the Indian provenances.

(b) Leaf dimensions (ii) - Leaf length:width ratio.

The Thai provenance, CR, produced greatest leaf length:width ratio but not significantly greater than K, whilst K and CR were significantly greater than MV.

(c) Leaf growth characteristics.

Thai provenance, CR, produced greatest leaf area followed in order of magnitude by K and MV (Table 9.2, Figure 9.7 B). Significant differences were found between CR and MV whilst the differences between CR and K and between K and MV were not significant.

There were non-significant differences in number of pairs of leaves although Indian provenances tended to be greater than Thai provenance.

In summary, there were clear differences in leaf characteristics between the Thai and Indian provenances examined. The Thai provenance was greater than the Indian provenances in leaf dimensions (length, width, area and length: width ratio) and total leaf area produced. There was little variation in number of pairs of leaves between the provenances. Some differences in leaf dimensions also existed between the Indian provenances.

9.4 Summary and Discussion

Please see p. 158.

Table 9.1 - Summarized details of analysis of variance of growth parameters of teak seedlings, grown under different temperatures, showing degrees of freedom, mean square values and significance levels.

Source of variation	Provenance (P)	Temp-T (^{o}C)	P X T	Error
Degrees of freedom	2	2	4	45
Overall growth				
Height growth (cm)	788.91^{***}	6206.30^{***}	98.29	148.00
Diameter growth (mm)	8.33	117.07^{***}	4.86	3.57
Total dry weight (gm)	404.33	4324.80^{***}	42.58	132.18
Growth analysis parameters				
Relative growth rate (mg mg^{-1} day^{-1})	0.0000851	0.0003547^{***}	0.0001271^{*}	0.0000466
Net assimilation rate (mg cm^{-2} day^{-1})	0.044712^{*}	0.000347	0.021692	0.009219
Leaf area ratio (cm^{2} gm^{-1})	1113.70^{***}	2869.00^{***}	178.64	187.36
Distribution of dry matter				
ln root/ln W	0.02098^{***}	0.00053	0.00610^{*}	0.00190
ln stem/ln W	0.00859^{***}	0.04217^{***}	0.00125	0.00093
ln leaf/ln W	0.001454^{***}	0.000076	0.000367	0.000146
ln shoot/ln root	0.02098^{***}	0.00053	0.00601^{*}	0.00190

Table 9.1 (Cont)

urce of variation	Provenance (P)	Temp-T (°C)	P X T	Error
grees of freedom	2	2	4	45
eaf characteristics				
ength of leaf 8 (cm)	270.77***	927.73***	30.75***	7.55
idth of leaf 8 (cm)	61.27***	201.94***	10.19***	2.41
rea of leaf 8(sq cm)	36325.00***	90298.00***	8013.50***	1048.80
eaf length:width atio	0.2323***	0.6009***	0.0584	0.0273
otal leaf area(sq cm)	3901700*	31061000***	705010	989330
umber of pairs of eaves	3.01	9.45***	1.63	1.51

* Significant at 5% level

*** Significant at 0.1% level

Other values are not significant at 5% level.

Table 9.2 - Mean values for overall growth, growth analysis parameters, distribution of dry weight and leaf characteristics of teak seedlings, grown under different temperature regimes for 91 days.

Parameters	Provenance (P)	Temperature-T (°C)			Average	LSD(5%)
		30/13	33/25	36/13		
Overall growth						
Height growth (cm)	CR	11.30	45.47	44.30	33.60	8.24(P,T)
	K	11.28	50.80	46.24	36.17	14.28(PXT)
	MV	6.37	37.22	26.87	23.49	
	Av	9.65	44.50	39.05		
Diameter growth (mm)	CR	6.73	13.46	11.44	10.54	1.28(P,T)
	K	8.00	11.20	10.60	9.93	2.22(PXT)
	MV	6.40	11.53	9.58	9.58	
	Av	7.04	12.06	10.54		
Total dry weight (gm)	CR	6.95	42.28	26.88	25.37	7.74(P,T)
	K	10.93	41.54	28.75	27.07	13.50(PXT)
	MV	5.23	33.17	15.80	18.07	
	Av	7.70	39.00	23.81		
Growth analysis parameters						
Relative growth rate (mg mg^{-1} day^{-1})	CR	0.0188	0.0298	0.0251	0.0246	0.0046(P,T)
	K	0.0290	0.0279	0.0283	0.0284	0.0079(PXT)
	MV	0.0189	0.0352	0.0301	0.0281	
	Av	0.0222	0.0309	0.0278		
Net assimilation rate (mg cm^{-2} day^{-1})	CR	0.2376	0.2569	0.2465	0.2470	0.0651(P,T)
	K	0.4144	0.2765	0.3444	0.3451	0.1127(PXT)
	MV	0.2703	0.3705	0.3056	0.3155	
	Av	0.3074	0.3013	0.2988		
Leaf area ratio (cm^{2}gm^{-1})	CR	79.8	88.92	93.67	84.86	9.28(P,T)
	K	57.03	76.63	73.96	69.21	16.08(PXT)
	MV	56.90	75.31	91.81	74.67	
	Av	61.97	80.29	86.39		

Table 9.2 (Contd)

Parameters	Provenance (P)	Temperature - T (^{o}C)			Average	LSD (5%)
		30/13	33/25	36/19		
istribution of dry atter						
ln root/ln W	CR	0.8277	0.8637	0.8623	0.8512	0.0175 (P,T)
	K	0.8938	0.8778	0.8815	0.8844	0.0303 (PXT)
	MV	0.8851	0.8913	0.8632	0.8799	
	Av	0.8689	0.8776	0.8690		
n stem/ln W	CR	0.7873	0.8612	0.8475	0.8320	0.0207 (P,T)
	K	0.7767	0.8602	0.8576	0.8315	0.0359 (PXT)
	MV	0.7276	0.8496	0.8035	0.7936	
	Av	0.7639	0.8570	0.8363		
ln leaf/ln W	CR	0.9443	0.9387	0.9366	0.9399	0.0082 (P,T)
	K	0.9161	0.9312	0.9202	0.9225	0.0142 (PXT)
	MV	0.9214	0.9229	0.9356	0.9266	
	Av	0.9273	0.9309	0.9308		
ln shoot/ln root	CR	1.1742	1.1278	1.1267	1.1429	0.0295 (P,T)
	K	1.0547	1.1036	1.0812	1.0798	0.0512 (PXT)
	MV	1.0675	1.0769	1.1193	1.0873	
	Av	1.0982	1.1028	1.1091		
Leaf character-.stics						
Length of leaf 8 (cm)	CR	11.46	30.63	22.20	21.43	1.86 (P,T)
	K	9.16	23.08	16.54	16.26	3.23 (PXT)
	MV	8.83	19.22	13.20	13.75	
	Av	9.82	24.31	17.31		
Width of leaf 8 (cm)	CR	5.13	14.37	12.21	10.57	1.05 (P,T)
	K	5.24	11.10	9.38	8.57	1.82 (PXT)
	MV	4.32	8.82	7.42	6.85	
	Av	4.90	11.43	9.67		
Area of leaf 8 (sq. cm)	CR	35.98	259.21	165.56	153.58	6.94 (P,T)
	K	31.59	155.50	96.86	94.65	12.02 (PXT)
	MV	24.26	105.50	63.47	64.41	
	Av	30.61	173.40	108.63		

Table 9.2 (Contd)

Parameters	Provenance (P)	Temperature-T (^{o}C)			Average	LSD(5%)
		30/13	33/25	26/19		
Leaf length:width ratio	CR	2.24	2.26	1.85	2.12	0.11(P,T)
	K	1.80	2.08	1.78	1.89	0.19(PXT)
	MV	2.06	2.24	1.79	2.03	
	Av	2.03	2.19	1.81		
Total leaf area (sq cm)	CR	493.11	3883.50	2548.20	2308.50	674.13(P,T)
	K	609.82	3044.80	1952.90	1869.17	1167.52(PXT)
	MV	297.76	2404.50	1404.60	1368.95	
	Av	466.89	3110.93	1968.57		
Number of pairs of leaves	CR	11.86	12.00	12.29	12.05	0.83(P,T)
	K	12.00	13.00	13.60	12.87	1.11(PXT)
	MV	11.17	13.00	13.50	12.56	
	Av	11.67	12.67	13.13		

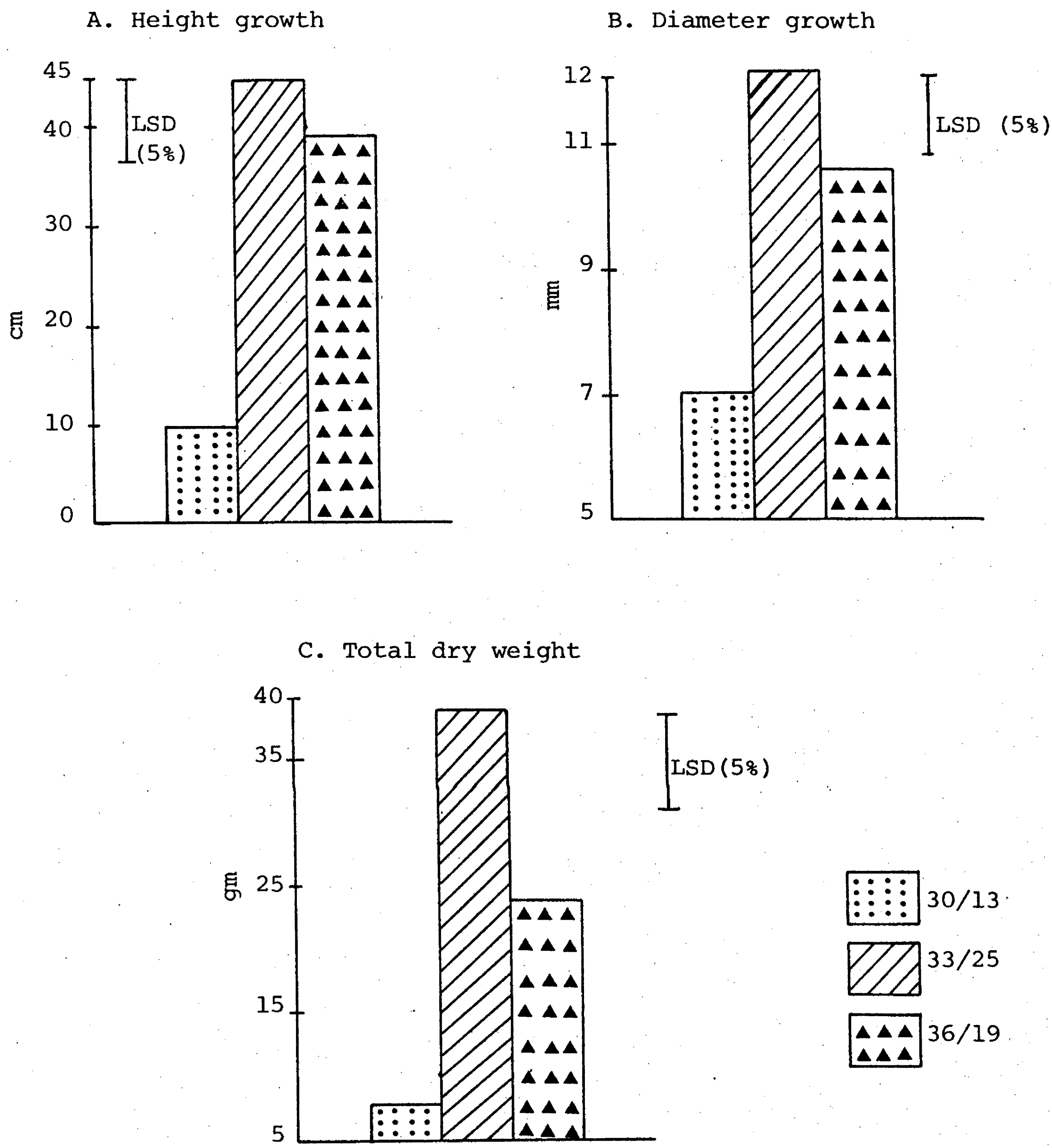
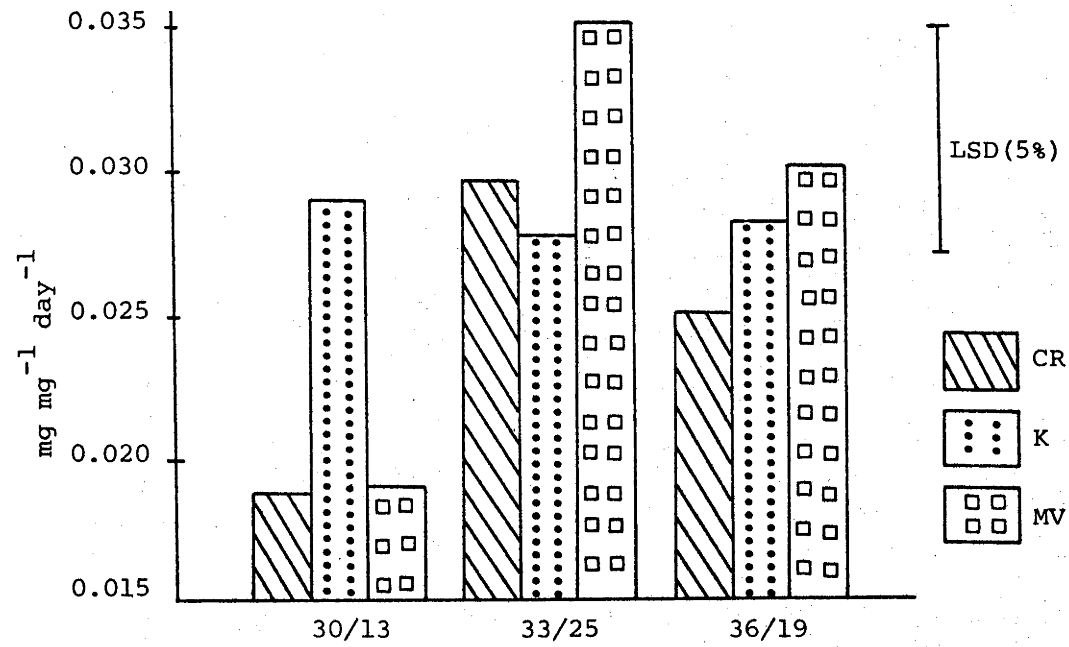


Figure 9.1 - Histograms showing the effect of temperature on height growth (A), diameter growth (B) and total dry weight (C) of teak seedlings in experiment 6.

A. RGR



B. LAR

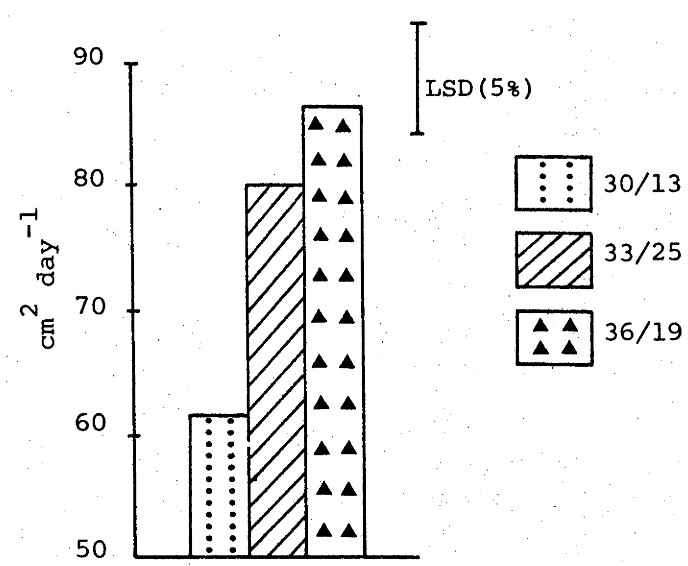


Figure 9.2 - Histograms showing the effect of temperature on RGR (A) and LAR (B) of one Thai (CR) and two Indian (K and MV) provenances in experiment 6.
CR = Chiengrai; K = Kerala; MV = Masale Valley

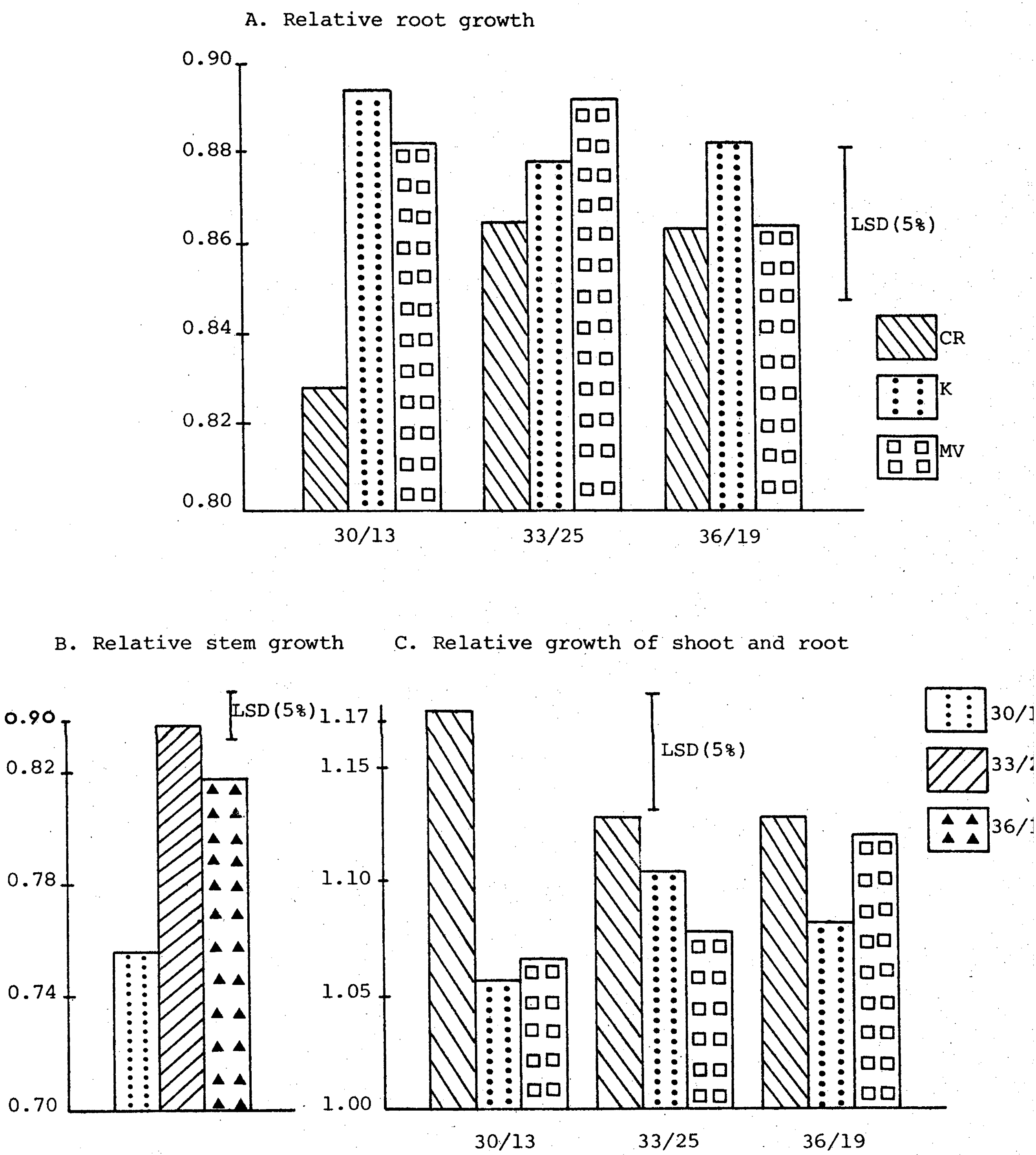


Figure 9.3 - Histograms showing the effect of temperature on relative root growth (A), relative stem growth (B) and relative growth of shoot and root of one Thai (**CR**) and two Indian (K and MV) provenances in experiment 6. Codes for provenances as in Table 4.1.

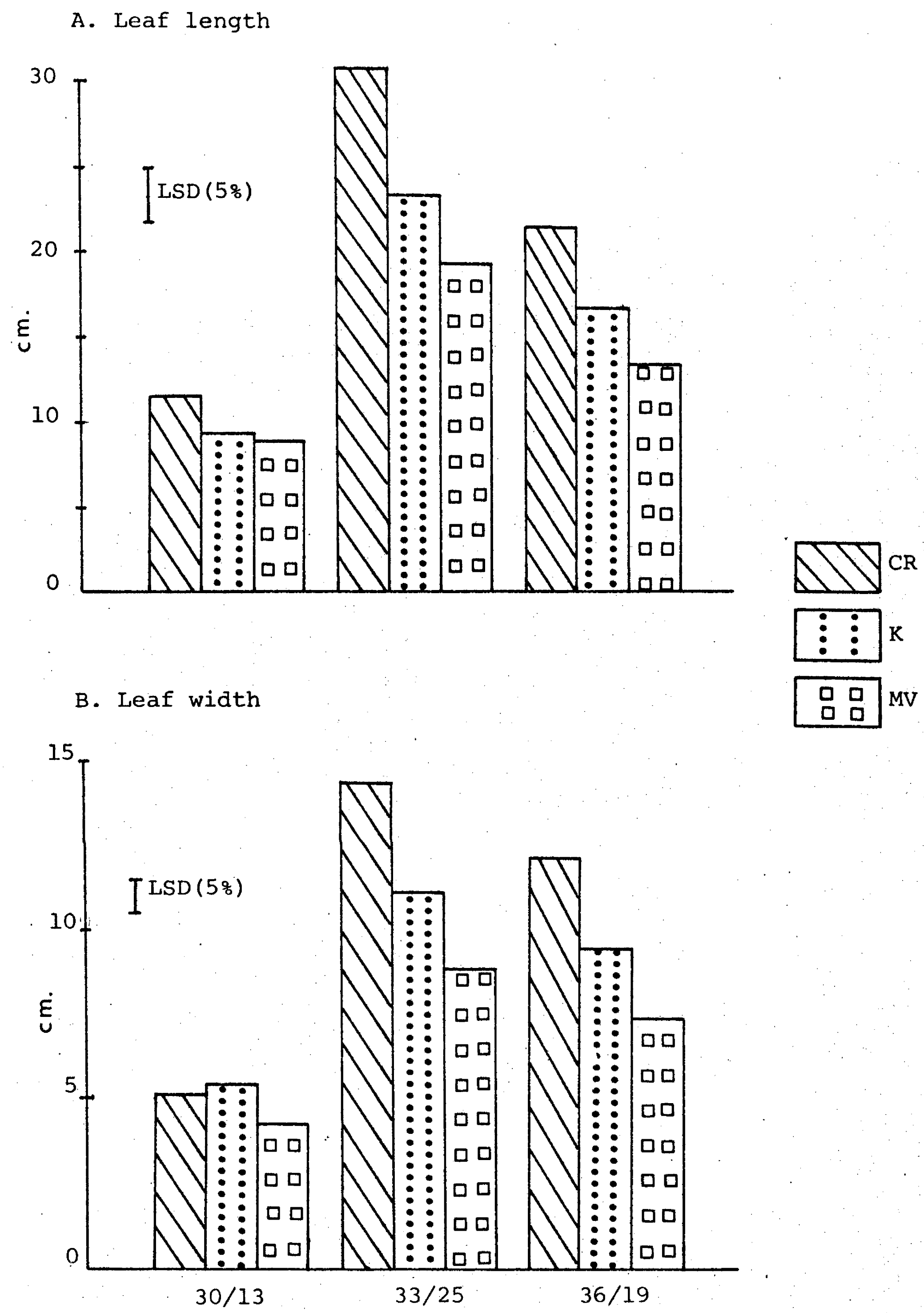
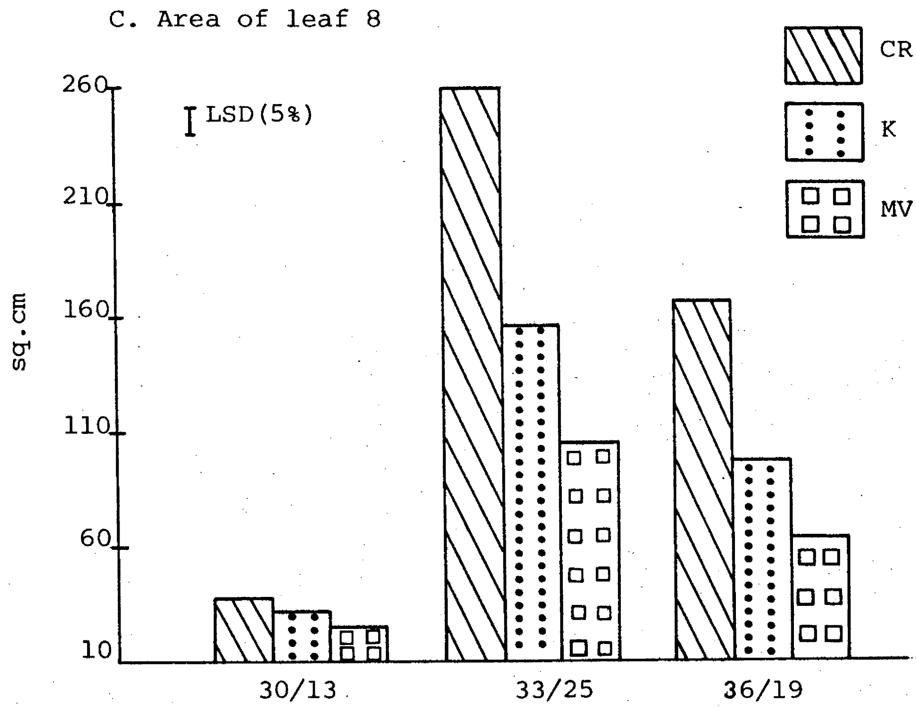
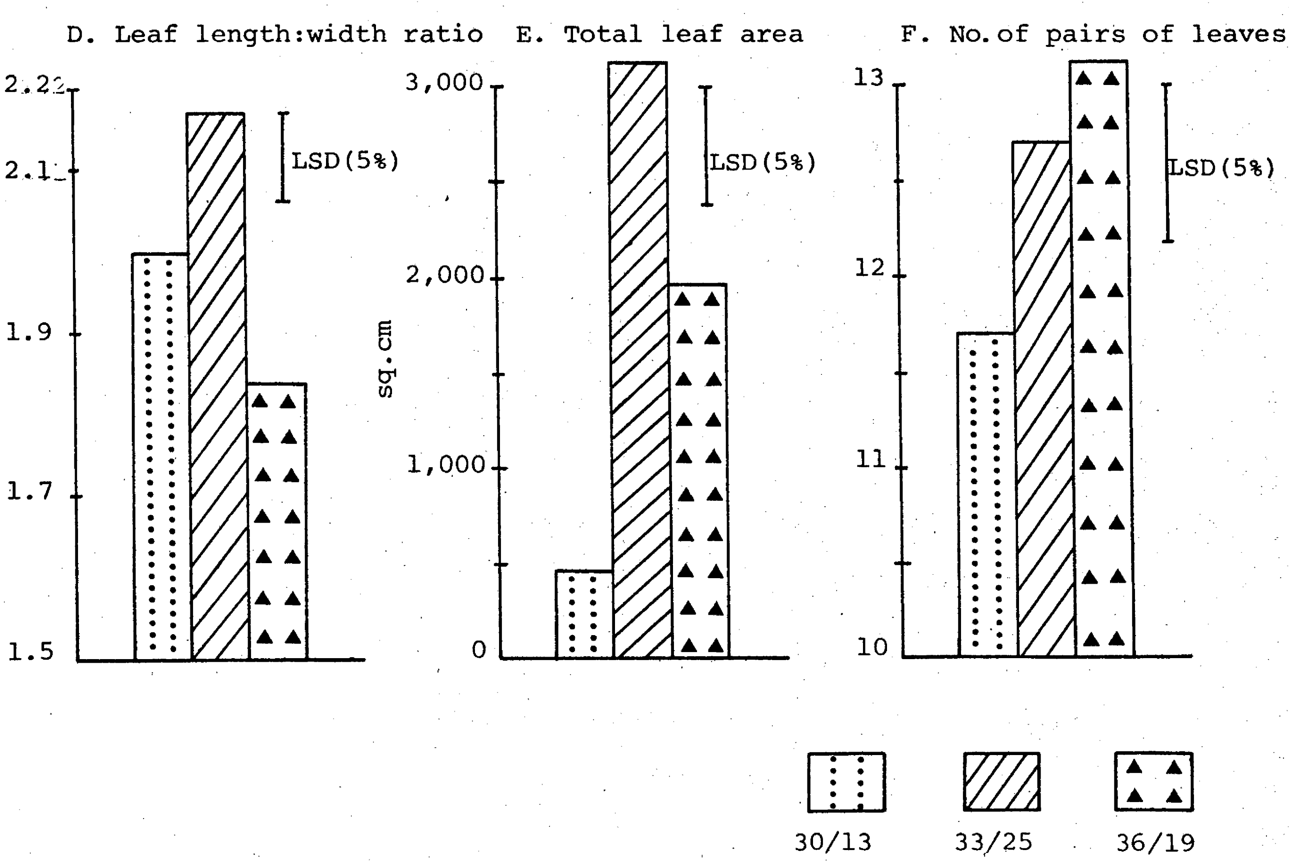


Figure 9.4 - Histograms showing the effect of temperature on six characteristics of leaf of one Thai (CR) and two Indian (K and MV) provenances in experiment 6. Codes for provenances as in Table 4.1.


C. Area of leaf 8
260
210
160
110
60
10
sq.cm
LSD(5%)
CR
K
MV
30/13
33/25
36/19


D. Leaf length:width ratio
2.22
2.1
1.9
1.7
1.5
LSD(5%)
E. Total leaf area
3,000
2,000
1,000
0
sq.cm
LSD(5%)
F. No.of pairs of leaves
13
12
11
10
LSD(5%)
30/13
33/25
36/19

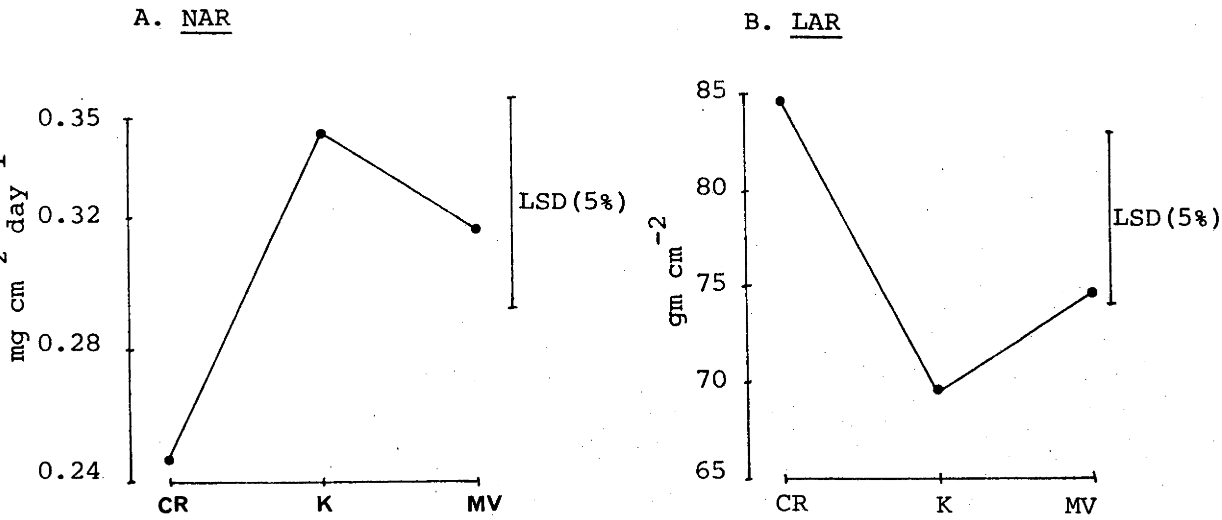


Figure 9.5 - Diagrams showing differences in NAR (A) and LAR (B) between one Thai (CR) and two Indian (K and MV) provenances. Temperatures pooled. Experiment. 6

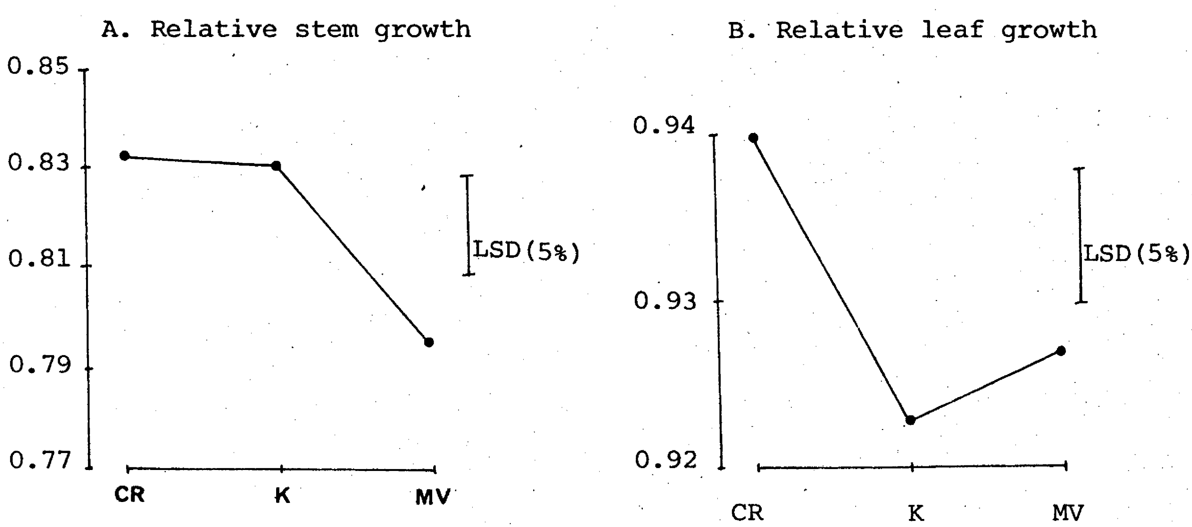


Figure 9.6 - Diagrams showing differences in relative stem growth (A) and relative leaf growth (B) of teak seedlings. Temperatures pooled. Experiment. 6

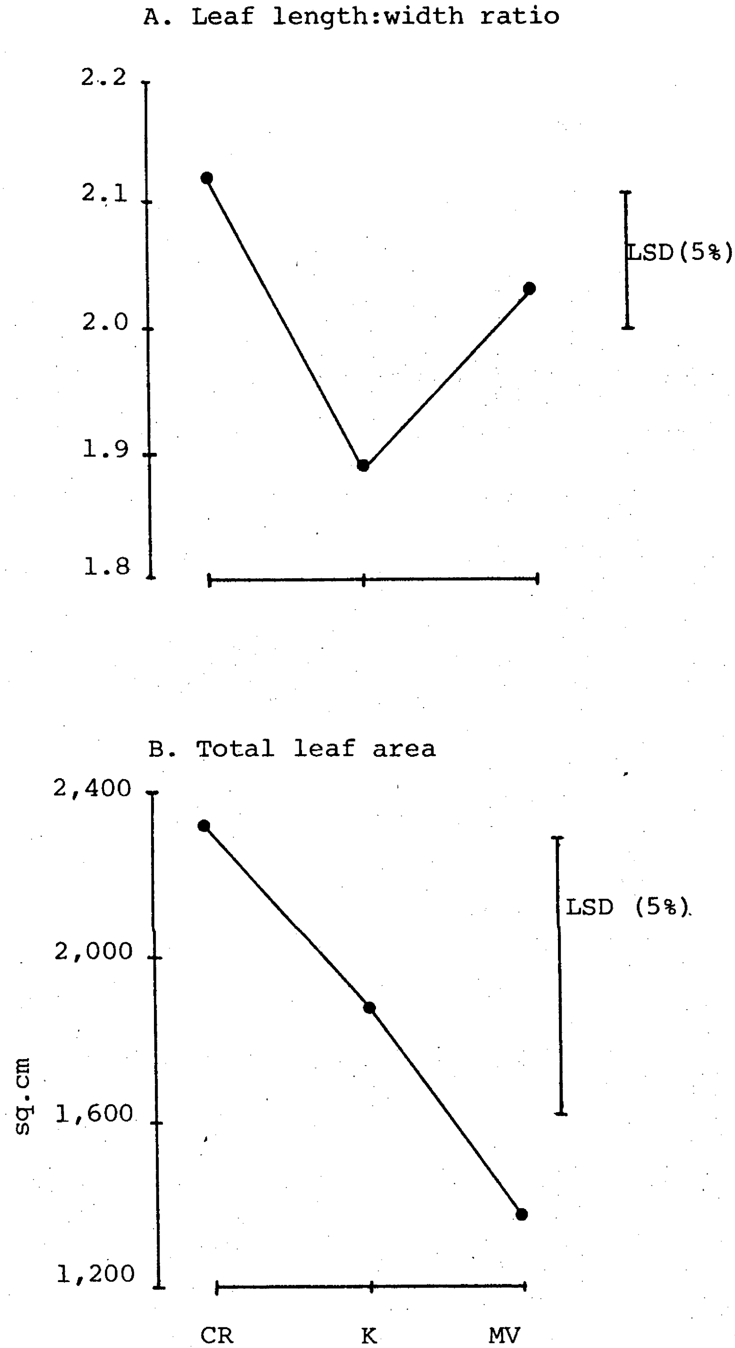


Figure 9.7 - Diagrams showing differences in leaf length:width ratio (A) and total leaf area (B) of teak seedlings in experiment 6.

9.4 Summary and Discussion

Effects of three temperatures(30/13, 33/25 and 36/19°C) on overall growth, growth analysis parameters, distribution of photosynthate between seedling parts and leaf characteristics of teak seedlings were investigated under phytotron controlled environments. One provenance from Thailand and two from India were used. The growth period was 91 days.

9.4.1 Effect of Temperature

Height growth, diameter growth and total dry weight were greatest at 33/25°C and poorest at 30/13°C. LAR and RGR had peaking values between 33/25 and 36/19°C whilst NAR was independent of temperature. Relative stem growth was greatest at 33/25°C and poorest at 30/13°C. Relative leaf growth did not differ with temperature and the effect of temperature on relative root growth was unclear.

Relative shoot growth with respect to root growth (i.e. shoot/root ratio) was highest at 33/25 and lowest at 30/13°C.

Leaf dimensions and total leaf area production were best at 33/25 and poorest at 30/13°C. The latter regime slowed the emergence of new leaves. Superiority in total leaf area were not related to number of leaves.

Responses of various growth parameters under night temperature ranging from 19 to 26°C and day/night temperature regime from 24/19 to 36/31°C have been reported in Chapters 6, 7 and 8 with the suggested optimum temperatures between 25 and 28°C (night) and between 30/25 and 33/28°C (day/night). In this experiment most parameters studied were greatest at 33/25°C. The results in this study therefore are in general agreement and it was concluded the optimum temperature for growth of teak seedlings under controlled conditions lies within the ranges 30 to 33°C for day temperature combined with 25 to 28°C for night temperature.

Results of growth analysis showed clearly dry matter production was not closely related to net assimilation rate but rather to leaf area ratio. Thus leaf area tends to control dry matter production.

The purpose of this study was to gain some knowledge of the growth behaviour of teak seedlings under the seasonal temperature variations of Northern Thailand. It was clear, as might be expected, growth was best in the rainy season (33/25°C) and was very reduced in the cold season (30/13°C). Height growth in the summer temperature regime (36/19°C) was not significantly poorer than that in the rainy season temperature regime (33/25°C). This indicates height growth could be maintained through all of the year except the cold period, i.e. for about nine months, provided other factors, e.g. soil moisture, were not limiting.

Growth was closely related to the development of leaves. At the winter temperature (30/13°C) leaf growth was poor due to both the slow production of new leaves and small leaf dimensions (see Section 8.5). During the cold season in Thailand the teak trees are deciduous. These results suggest leaf shedding is advantageous. Very little growth could occur at these temperatures in any cases and shedding of leaves must presumably reduce respiration losses.

9.4.2 Provenance Differences

There were few differences between Thai provenance (CR) and one Indian provenance (K). These provenances only differed in net assimilation rate, leaf area ratio and leaf dimensions. In contrast, the other Indian provenance (MV) was generally poorer than the Thai material. This provenance had also high net assimilation rates and smaller leaves compared to the Thai material.

There appears to be a difference between the two Indian provenances in their suitability to the Thai temperature conditions. Neither proved superior to the Thai material under any of the seasonal conditions as leaf area appeared to be important in determining growth and their smaller leaf size may indicate reduced suitability for Thai conditions.

CHAPTER 10

Provenance Differences in Teak (Tectona grandis L.f.)

10.1 Introduction

The effects of temperature and daylength were examined in four experiments (experiments 3, 4, 5 and 6) and the results obtained have been described previously from Chapter 6 to Chapter 9. In these four experiments comparisons between provenances were included. This chapter summarizes the results of provenance differences recorded in the experiments 3, 4, 5 and 6.

Some experiments were conducted to determine the extent of provenance variation within Thailand. In other experiments the variation between Thai and Indian provenances were investigated. Full details of the provenances used have been given in Table 4.1. The arrangements are summarized in Table 10.1.

Because it is important to determine the existence of regional differences as well as simple provenance differences the results of each experiment reported here are presented as:

(i) Within - Thailand differences

(ii) Thai vs Indian differences.

Comparisons of provenances were made in four terms of:

(i) Overall growth,

(ii) Growth analysis parameters,

(iii) Distribution of dry matter,

(iv) Leaf characteristics.

10.2 Overall Growth (Height Growth, Diameter Growth and Total Dry Weight)

10.2.1 Thai Provenances

Two Thai provenances, one from the northern region (CR) and one from the central region (SK) were compared in three experiments. The results for height growth, diameter growth and total dry weight have been described earlier in Chapter 6 (see below for specific sections) and are summarized here in Table 10.2.

The two provenances generally did not differ significantly in height or total dry weight. There were however, some effects on diameter growth (experiment 4), as noted in Chapter 6 (Section 6.2.2). SK was better than CR at shorter daylength but not at the longer day (Tables 6.4 and 10.2, Figure 6.1C). Also in experiment 5 SK was significantly better than CR in diameter growth at the low temperature regime (24/19^{o}C) but not at the higher regimes (30/25, 33/28 and 36/31^{o}C) (Table 6.6 and 10.2, Figure 6.2B).

Experiment 3 showed there were definite differences between the Thai provenances. Of the five compared three (CR, SK and SSA) did not differ in diameter growth or total dry weight but SSA had superior height growth (Table 6.2 and 10.2, Figure 10.1A, B and C). Of the other two provenances TK was always poorest of the five and SO generally intermediate between TK and the other three in all three parameters, although the differences were not all statistically significant.

CR, SSA and SO are from Northern Thailand whilst SK and TK are from Central Thailand. Thus, although definite differences in height growth, diameter growth and total dry weight existed between the Thai provenances these could not be related to specific regions.

10.2.2 Thai vs Indian Provenances

Analysis of the results obtained in experiment 5 for height growth and diameter growth showed a significant interaction between provenance and temperature regime (Table 6.5).

There were generally no significant differences in height and diameter growth between the two Thai provenances (CR and SK) and one Indian (K). This Indian provenance (K) was not significantly poorer than the Thai provenances in diameter growth and was only significantly poorer in height growth than one of the Thai provenances (CR) at the highest temperature regime (36/31^{o}C) (Table 6.6 and 10.2, Figure 6.2A and B). The other Indian provenance (MV) gave poorest height growth and diameter growth throughout except at 33/28^{o}C (Table 6.6 and 10.2, Figure 6.2A and B). At this temperature it did not differ significantly from the others. Therefore differences in both height and diameter growth between provenances varied with temperature regime with no clear differences between the Thai and Indian materials.

There were very highly significant differences between provenances in dry matter production in experiment 5 (Table 6.5). CR and K did not differ significantly but K was significantly greater than SK. SK and MV did not differ significantly (Table 6.6 and 10.2, Figure 10.3A).

In experiment 6 provenance differences were evident only in height growth with CR and K being significantly greater than MV (Table 9.2 and 10.2). Thus this agreed with the results obtained for height growth between these three provenances in experiment 5.

10.3 Growth Analysis Parameters

Growth analysis studies were only made in experiments 4 and 6.

10.3.1 Thai Provenances

The two Thai provenances, one from Northern Thailand (CR) and one from Central Thailand (SK) were compared under different night temperatures and daylengths in experiment 4 (see Section 6.1). There were no significant differences in relative growth rate (RGR) and net assimilation rate (NAR) between the provenances (Table 6.4). Differences in LAR were clear although there was a significant provenance x daylength interaction (Table 6.3). CR was significantly greater than SK in LAR at both 9.5 h and 11 h daylengths but not at 14 h (Table 6.4, Figure 6.3C). Thus RGR and NAR did not differ between the Thai provenances compared and the differences in LAR were effected by daylength.

10.3.2 Thai vs Indian Provenances

One provenance from Thailand (CR) was compared with two provenances from India (K and MV) in experiment 6.

There was a significant provenance x temperature interaction in RGR (Table 9.1). However, differences occurred only at the lowest temperature (30/13^{o}C). At this temperature K was significantly greater than both CR and MV which did not differ significantly (Table 9.2, Figure 9.2A).

There were clear differences in both NAR and LAR between the provenances used. The Thai provenance was lower in NAR but greater in LAR (Table 9.2, Figure 9.5A and B). The differences in both NAR and LAR were not significant between the two Indian provenances (K and MV).

Thus the Thai provenance had lower NAR but greater LAR than the Indian materials.

10.4 Distribution of Dry Matter (experiments 4, 5 and 6)

10.4.1 Thai Provenance

Two Thai provenances, one from Northern Thailand and one from Central Thailand were compared in experiments 4 and 5. There were no differences in relative stem growth (ln stem/ln W) and relative growth of shoot and root between the provenances (Table 7.1, 7.4 and 10.3). Results for relative leaf growth (ln leaf/ln W) showed SK was significantly greater than CR in experiment 4 (Table 7.2 and 10.3, Figure 10.2C) but only at the 24/19^{o}C regime in experiment 5 (Table 7.4 and 10.3, Figure 7.2C). Relative root growth values (ln root/ln W) did not differ between the provenances in the two experiments except at the 33/28^{o}C regime in experiment 5 at which CR was significantly greater than SK (Table 7.2 and 10.3, Figure 7.2A).

Thus distribution of photosynthate between stem, roots, leaves and between shoot and root did not generally differ between the two Thai provenances.

10.4.2 Thai vs Indian Provenances

Two Thai (CR and SK) and two Indian (K and MV) provenances were compared under four different temperature regimes (24/19, 30/25, 33/28 and 36/31^{o}C). Results obtained for ln root/ ln W, ln stem/ln W and ln leaf/ln W showed a very highly significant interaction between provenance and temperature regime (Table 7.3).

One Indian provenance (MV) exhibited a different pattern of photosynthate distribtuion to the others. In this provenance the values for relative root growth (ln root/ln W) were highest (Table 7.4 and 10.3, Figure 7.2A) and the relative leaf growth (ln leaf/ln W) were lowest under all four temperature regimes (Table 7.4 and 10.3, Figure 7.2C). The differences were however not always significant. MV also showed low relative stem growth (ln stem/ln W) at three temperature regimes (24/19, 30/25 and 36/31^{o}C) but not at 33/28^{o}C (Table 7.4 and 10.3, Figure 7.2B).

The other provenances did not differ except at the high temperature regime of 36/31^{o}C. At this temperature the Indian provenance (K) had significantly greater relative root growth and significantly poorer relative leaf growth than the two Thai provenances (CR and SK) (Table 7.4 and 10.3, Figure 7.2A and C). Thus at the high temperature regime differences in photosynthate distribution occurred with the Thai provenance having greater leaf development and the Indian provenances greater root development.

There were also very highly significant differences in relative growth of shoot and root (ln shoot/ln root) in experiment 5 (Table 7.3). The Indian provenances (K and MV) showed a tendency to be lower than the Thai provenances (CR and SK) (Table 7.4 and 10.2, Figure 10.3B). One of the Indian provenances (MV) was significantly poorer than the other three provenances.

In experiment 6 three provenances common to those tested in experiment 5, one from Northern Thailand (CR) and two from India (K and MV) were examined under three temperature regimes (30/13, 33/25 and 36/19^{o}C).

The Indian provenances (K and MV) had greater relative root growth and lower relative stem growth and relative leaf growth values than the Thai (CR) at all three temperature regimes but the differences were not always significant (Table 9.2 and

10.3, Figure 9.3A, 9.6A and B). Relative root growth of the Indian provenances differed significantly from that of the Thai provenance at 30/13^{o}C and Indian provenance (K) always had lower relative stem growth and relative leaf growth than both other provenances.

Relative growth of shoot and root (ln shoot/ln root) was affected by a significant interaction between provenance and temperature regime (Table 9.1). Although the ln shoot/ln root figures for the Thai provenance (CR) were always greater than those for the Indian provenances (K and MV) at all three temperature regimes (30/13, 33/25 and 36/19^{o}C), significant differences were found only at the lowest temperature regime (30/13^{o}C). (Table 9.2 and 10.3, Figure 9.3C).

10.5 Leaf Characteristics (experiments 3,4,5 and 6)

Leaf characteristics examined were summarized in Table 10.4.

10.5.1 Total Leaf Area

10.5.1.1 Thai Provenances

One provenance from Northern Thailand (CR) was compared with one provenance from Central Thailand (SK) in experiments 3,4 and 5.

Generally, there were no differences in leaf area between the provenances (CR and SK) in experiments 3 and 5, but in experiment 4 SK had significantly greater leaf area than CR (Table 8.4 and 10.5, Figure 10.2D).

There were significant differences in leaf area between some of the five Thai provenances (CR, SO, SSA, SK and TK) compared in experiment 3. SSA and SK did not differ significantly but were both significantly greater than SO and

TK which also did not differ (Table 8.2 and 10.5, Figure 10.1D). CR was intermediate.

10.5.1.2 Thai vs Indian Provenances

Two Thai provenances (CR and SK) were compared with two Indian provenances (K and MV) in experiment 5 and one of the Thai provenances (CR) was compared with the Indian provenances in experiment 6.

Results obtained for leaf area in experiment 6 showed a very highly significant provenance x temperature regime interaction (Table 8.5). There were some clear differences in leaf area between the Thai and Indian provenances at particular temperatures. At the higher temperatures (33/28 and 36/31^{o}C) the Thai provenances (CR and SK) were definitely greater than the Indian provenances (K and MV), (Table 8.6 and 10.5, Figure 8.2D). This pattern also occurred at 30/25^{o}C but the differences were less definite than at the higher temperature range. At the lowest temperature (24/19^{o}C) differences were not significant.

In experiment 6 the same differences in leaf area were clear and very highly significant (Table 9.1). The Thai provenance (CR) was greater than the Indian (K and MV) (Table 9.2 and 10.5, Figure 9.7B).

Thus the Thai provenances were generally greater than Indian provenances in leaf area at the higher temperatures.

10.5.2 Leaf Dimension (i) - Length, Width and Area of Particular Leaves

10.5.2.1 Thai Provenances

In experiments 3, 4 and 5 two Thai provenances, one from Northern Thailand (CR) and one from Central Thailand (SK) were compared.

In all three experiments, the Central provenance (SK) always had longer and wider leaves than the Northern provenance (CR). However, significant differences were found only in experiment 4 (Table 8.4 and 10.5, Figure 10.2E and F). In experiment 5 values for leaf width obtained over a high temperature range (30/25, 33/28 and 36/31^{o}C) were significantly different (Table 8.6 and 10.5, Figure 8.2C).

The differences in individual leaf width between the five Thai provenances (CR, SO, SSA, SK and TK) compared in experiment 3 were similar to the differences recorded for total leaf area (Section 10.5.1.1). SSA and SK had wider leaves, SO and TK narrow leaves and CR intermediate (Table 8.2 and 10.5, Figure 10.1E). Differences in leaf length did not exist between the five provenances.

Thus there was wide variation in leaf width between the Thai provenances tested but less clear differences in leaf length. There was no evidence of regional differences in leaf dimensions.

10.5.2.2 Thai vs Indian Provenances

Two Thai provenances (CR and SK) were compared with two Indian provenances (K and MV) in experiment 5 and CR with K and MV in experiment 6.

In experiment 5 there was a very highly significant interaction between provenance and temperature regime in length, width and area of leaf 8 (Table 8.5).

There were definite differences between the Thai and Indian provenances at the high temperatures. Under the 33/28 and 36/31^{o}C regimes leaf 8 in Thai provenances (CR and SK) was significantly greater than in the Indian provenances (K and MV) in length, width and area (Table 8.6 and 10.5, Figure 8.2B, C and D). At the 30/25^{o}C regime the Thai provenance showed a tendency to be greater than the Indian provenances in leaf length but not at 24/19^{o}C. Differences in both leaf width and leaf area were unclear at the regimes 24/19 and 30/25^{o}C.

There was a similar pattern in experiment 6. The Thai provenance (CR) was always greater than K and MV in the three leaf characteristics at all temperature regimes (30/13, 33/25 and 36/19^{o}C) with significant differences at the higher regimes (33/25 and 36/19^{o}C) but not at the low regimes (30/13) (Table 9.2 and 10.5, Figure 9.4A, B and C).

10.5.3 Leaf dimensions (ii) - Leaf Length:Width Ratio of Particular Leaves

10.5.3.1 Thai Provenances

Two Thai provenances, CR and SK, were compared in experiments 3, 4 and 5.

CR had generally greater values for the leaf length: width ratio in experiments 3 and 4. Significant differences were found in experiment 3 but in experiment 4 only at the high night temperature (26^{o}C) (Table 8.2, 8.4 and 10.5, Figure 10.1F).

Generally in experiment 5 although the differences were not significant the values recorded for CR were always greater except at the highest temperature (36/31^{o}C) (Table 8.6 and 10.5, Figure 8.2E). Thus the Northern provenance (CR) was greater than the Central provenance (SK). This agreed with the results determined for leaf length and leaf width above (Section 10.5.2.1).

Five Thai provenances (CR, SO, SSA, SK and TK) were examined in experiment 3. SK was significantly poorer than the other four which did not differ significantly. This reflects the generally greater leaf width of the SK provenance (Section 10.5.2.1).

10.5.3.2 Thai vs Indian Provenances

The Thai provenance (CR) had significantly greater leaf length:width ratio than the Indian (K and MV) in experiment 6 (Table 9.2 and 10.5, Figure 7.2A). The differences in experiment 5, were, however, not clear. This probably reflected the changes in leaf dimensions at different temperature regimes.

10.5.4 Leaf Growth Characteristics - Rate and Duration of Elongation, the Number of Pairs of Leaves Present and Frequency of Production of Leaves

Four provenances, two from Thailand (CR and SK) and two from India (K and MV) were compared only in experiment 5. Although the results obtained for rate and duration of elongation and frequency of production each showed a significant interaction between provenance and temperature regime (Table 8.5) there were some trends apparent particularly at the higher temperatures. Under the 33/28 and 36/31^{o}C regimes the Thai provenances (CR and SK) showed more rapid leaf elongation and a longer period of elongation of a single leaf (Table 8.6 and 10.5, Figure 8.2F and G). At lower temperatures (24/19 and 30/25^{o}C) this pattern was not evident.

No clear trends could be determined for the time interval between the production of leaf pairs (Table 8.6 and 10.5, Figure 8.2I). However, the number of pairs of leaves produced was significantly greater in the Indian provenances than the Thai (Table 8.6 and 10.5, Figure 10.3C).

10.5.5 Summary of Leaf Studies

(a) Thai Provenances

(i) Differences in total leaf area and leaf width of particular leaves occurred between Thai provenances but differences in leaf length of particular leaves were less clear.

(ii) One provenance SK had a low leaf length:width ratio.

(b) Thai vs Indian Provenances

(i) Thai provenances were generally greater than the Indian provenances in total leaf area and leaf dimensions (length, width and area of particular leaves) at high temperature regimes (33/25, 33/28, 36/19 and 36/31°C).

(ii) Differences in leaf shape between Thai and Indian provenances were not clear.

10.6 Summary and Discussion

Please see p. 187.

Table 10.1 - Summarized teak proveances compared in experiments 3, 4, 5 and 6.

Experiments	Thai provenances					Indian Provenances		Treatments
	Northern			Central				
	CR	SO	SSA	SK	TK	K	MV	
3	✓	✓	✓	✓	✓	-	-	Three treatments - day temperature 30°C x night temperatures 19, 22 and 26°C.
4	✓	-	-	✓	-	-	-	Nine combinations - day temperature 30°C x three night temperatures 19, 22 and 26°C x three day-lengths 9.5, 11 and 14 h.
5	✓	-	-	✓	-	✓	✓	Four treatments - day/night temperature regimes 24/19, 30/25, 33/28 and 36/31°C.
6	✓	-	-	-	-	✓	✓	Three treatments - day/night temperature regimes 30/13 (winter), 33/25 (rainy season) and 36/19 (summer).

Note: CR = Chiengrai; SO = Mae Gah Seed Orchard; SSA = TIC Seed Source Area No. 1;
SK = Sukhothai; TK = Tak; K = Kerala; MV = Masale Valley.

Table 10.2 - Summarized results obtained for provenance differences in height growth, diameter growth and total dry weight in experiments 3, 4, 5 and 6.

Parameters	Provenance differences(1)				
Experiment 3					
Height growth	SSA	CR	SK	SO	TK
Diameter growth	SSA	CR	SK	SO	TK
Total dry weight	SK	SSA	CR	SO	TK
Experiment 4					
Height growth	SK	CR			
Diameter growth(2)	SK	CR			
Total dry weight	SK	CR			
Experiment 5	24/19	30/25	33/28	36/31	
Height growth(3)	CR K SK MV	K CR SK MV	CR K MV SK	CR SK K MV	
Diameter growth(3)	SK K CR MV	SK CR K MV	CR SK MV K	SK CR K MV	
Total dry weight	K	CR	SK	MV	

Table 10.2 (Contd)

Parameters	Provenance differences		
Experiment 6			
Height growth	K	CR	MV
Diameter growth	CR	K	MV
Total dry weight	K	CR	MV

(1) Provenances not connected by either a horizontal or a vertical bar are significantly different at 5% level.

(2) Provenance x daylength interaction. The differences presented were at 9.5 h; the differences at other daylengths (11 and 14 h) were not significant.

(3) Provenance x temperature regime interaction.

Table 10.3 - Summarized results obtained for provenance differences in distribution of dry matter between roots, stem, leaves and shoot in experiments 4, 5 and 6.

Parameters	Provenance differences[1]			
<u>Experiment 4</u>				
ln root/ln W	SK CR			
ln stem/ln W	SK CR			
ln leaf/ln W	SK CR			
ln shoot/ln root	SK CR			
<u>Experiment 5</u>[2]	24/19	30/25	33/28	36/31
ln root/ln W[2]	MV CR SK K	MV K SK CR	MV K CR SK	MV K SK CR
ln stem/ln W	CR K SK MV	K CR SK MV	CR MV SK K	CR K SK MV
ln leaf/ln W[2]	K SK CR MV	CR SK K MV	SK CR K MV	SK CR K MV
ln shoot/ln root	CR SK K MV			
<u>Experiment 6</u>	30/13	33/25	36/19	
ln root/ln W[2]	K MV CR	MV K CR	K MV CR	
ln stem/ln W	CR K MV			

Table 10.3 (Contd)

Parameters	Provenance differences [1]
ln leaf/ln W	CR MV K
ln shoot/ln root [2]	30/13: CR, MV, K 33/25: CR, K, MV 36/19: CR, MV, K

(1) Provenances not connected by either a horizontal or a vertical bar are significantly different at 5% level.

(2) Provenance x temperature regime interaction.

Table 10.4 - Summarized studies of provenance differences in leaf characteristics in experiments 3, 4, 5 and 6.

Characteristics	Leaf pairs used				Experiments included			
	Experiments							
	3	4	5	6	3	4	5	6
Total leaf area	All	All	All	All	✓	✓	✓	✓
<u>Leaf dimensions (i)</u>								
Leaf length	6th	5th	8th	8th	✓	✓	✓	✓
Leaf width	6th	5th	8th	8th				
Leaf area	-	-	8th	8th	-	-	✓	✓
<u>Leaf dimensions (ii)</u>								
Leaf length width ratio	6th	5th	8th	8th	✓	✓	✓	✓
<u>Leaf growth</u>								
Rate of leaf elongation	-	-	8th	-	-	-	✓	-
Duration of leaf elongation	-	-	8th	-	-	-	✓	-
Frequency of leaf pairs production	-	-	7-8th	-	-	-	✓	-
Number of pairs of leaves present at 91 days	-	-	8th	-	-	-	✓	-

Table 10.5 - Summarized results obtained for provenance differences in leaf characteristics in experiments 3, 4, 5 and 6.

Characteristics	Provenance differences(1)			
<u>Experiment 3</u>				
Total leaf area	SSA SK CR SO TK			
<u>Leaf dimensions (i)</u>				
Leaf length	SSA SK CR TK SO			
Leaf width	SK SSA CR TK SO			
<u>Leaf dimensions (ii)</u>				
Leaf length:width ratio	SO CR TK SSA SK			
<u>Experiment 4</u>				
Total leaf area	SK CR			
<u>Leaf dimensions (i)</u>				
Leaf length	SK CR			
Leaf width	SK CR			
<u>Leaf dimensions (ii)</u>				
Leaf length:width ratio(2)	19	22	26	
	CR SK	CR SK	CR SK	
<u>Experiment 5</u>	24/19	30/25	33/28	36/31
Total leaf area (3)	K SK CR MV	CR SK K MV	CR SK K MV	CR SK K MV

Table 10.5 (Contd)

Characteristics	Provenance differences (1)			
<u>Leaf dimensions</u> (i)	24/19	30/25	33/28	36/31
Leaf length$^{(3)}$	SK CR K MV	SK CR K MV	SK CR K MV	SK CR K MV
Leaf width $^{(3)}$	K SK CR MV	SK K CR MV	SK CR K MV	SK CR K MV
Leaf area$^{(3)}$	K SK CR MV	SK K CR MV	SK CR K MV	SK CR K MV
<u>Leaf dimensions</u> (ii)				
Leaf length:width ratio$^{(3)}$	CR MV SK K	CR MV SK K	MV CR K SK	MV K SK CR
<u>Leaf growth</u>				
Rate of leaf enlongation$^{(3)}$	K CR SK MV	SK CR K MV	SK CR K MV	SK CR K MV
Duration of leaf elongation (3)	CR K MV SK	SK CR MV K	SK CR MV K	CR SK MV K
Frequency of leaf pairs production (3)	CR MV SK K	CR SK MV K	SK CR K MV	SK K CR MV
Number of pairs of leaves present at 91 days	MV	K	CR	SK

Table 10.5 (Contd)

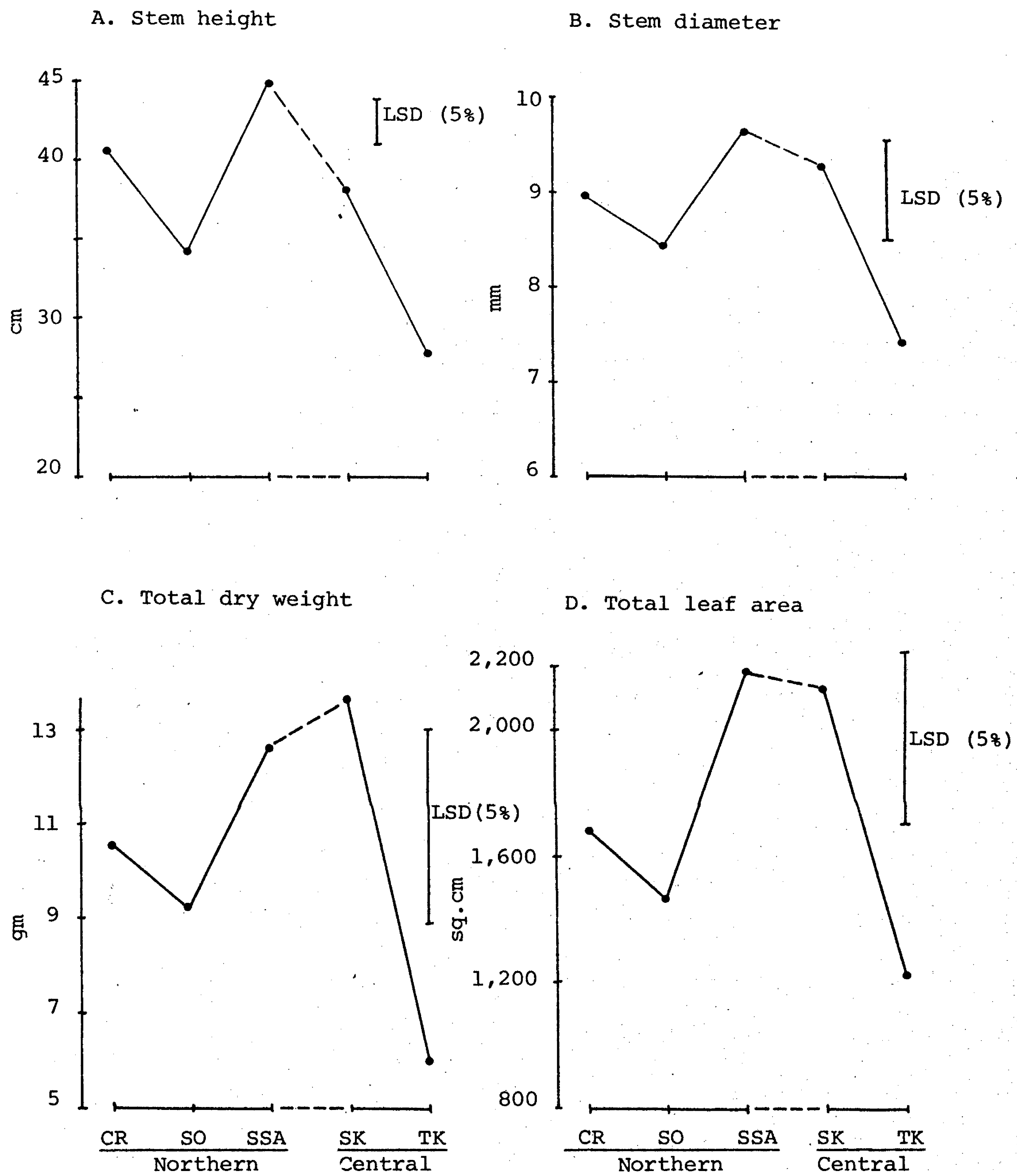
Characteristics	Provenance differences (1)		
<u>Experiment 6</u>			
Total leaf area	CR	<u>K</u>	<u>MV</u>
<u>Leaf dimensions</u> (i)	30/13	33/25	36/31
Leaf length (3)	CR K MV	CR K MV	CR K MV
Leaf width(3)	CR K MV	CR K MV	CR K MV
Leaf area(3)	CR K MV	CR K MV	CR K MV
<u>Leaf dimensions</u> (ii)			
Leaf length:width ratio	CR	<u>K</u>	<u>MV</u>

(1) Provenances not connected by either a horizontal or a vertical bar are significant at 5% level.

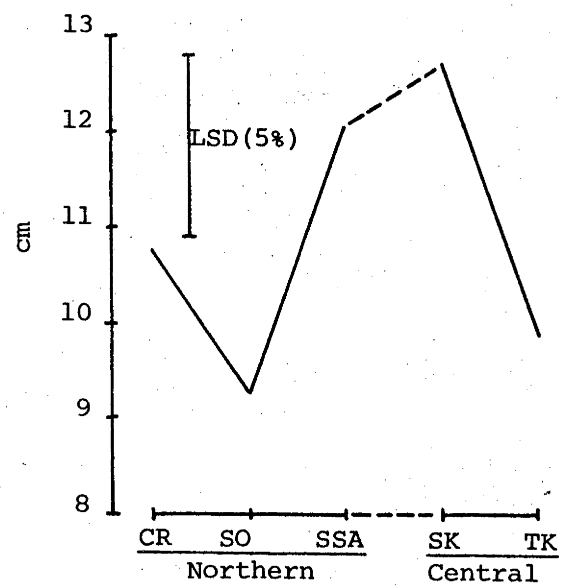
(2) Provenance x night temperature interaction.

(3) Provenance x temperature regime interaction.

Figure 10.1 (For details see page 183)



E. Leaf width



F. Leaf length:width ratio

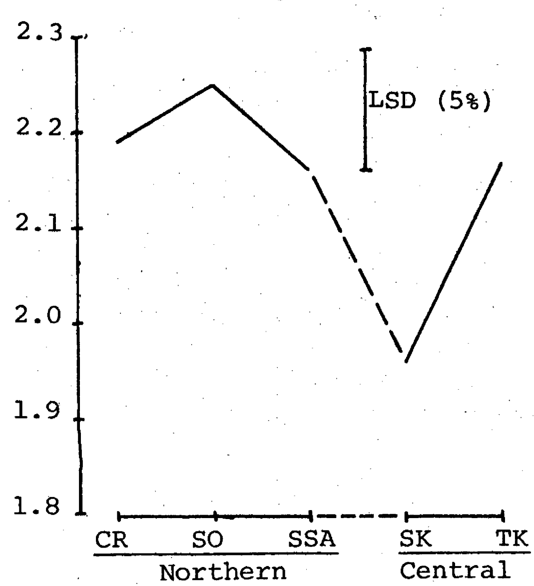
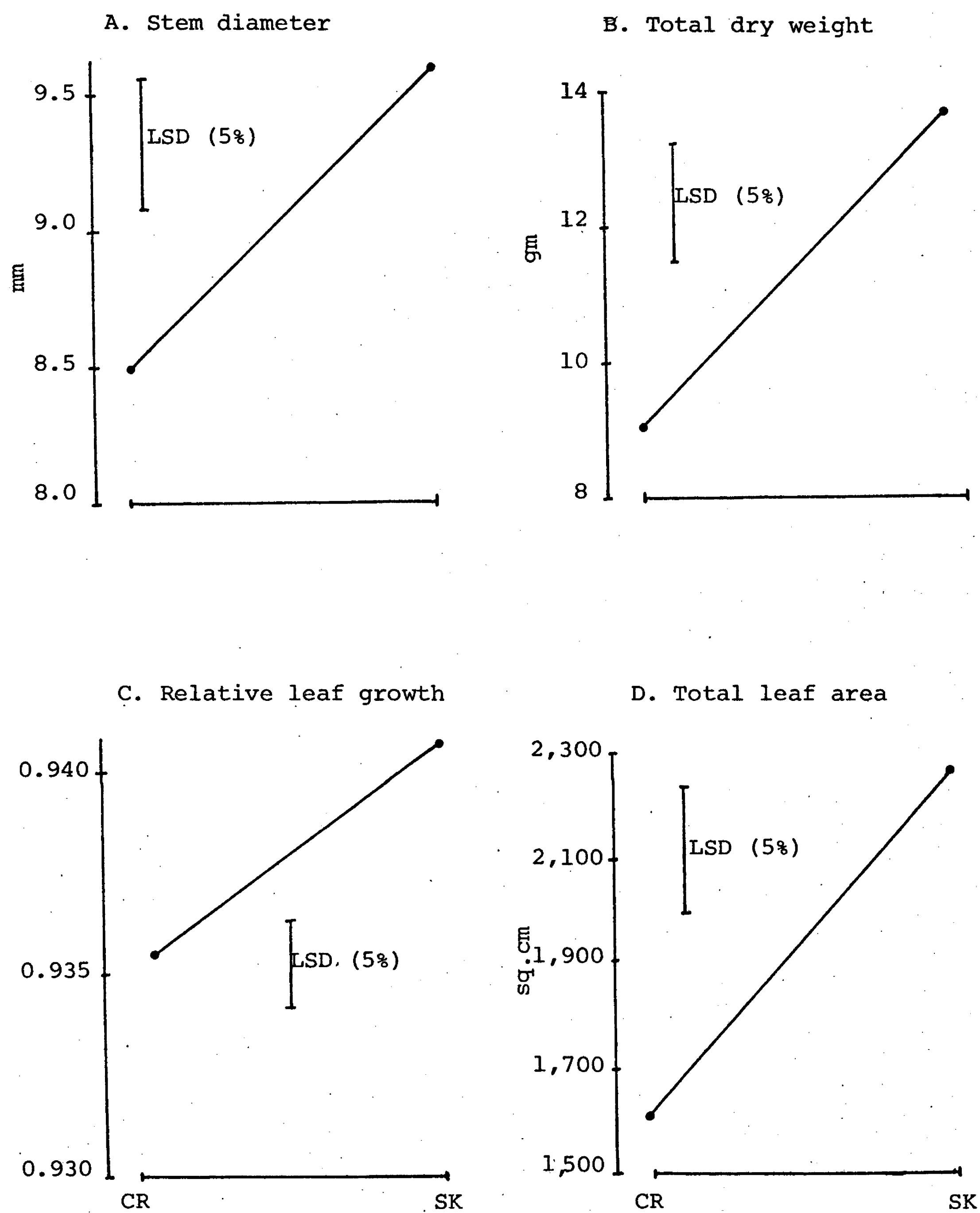


Figure 10.1 - Diagrams showing differences in stem height (A), stem diameter (B), total dry weight (C), total leaf area (D), leaf width (E) and leaf length:width ratio (F) between five Thai provenances in experiment 3. Codes for the provenances were given in Table 4.1.

Figure 10.2 (For details see page 185)



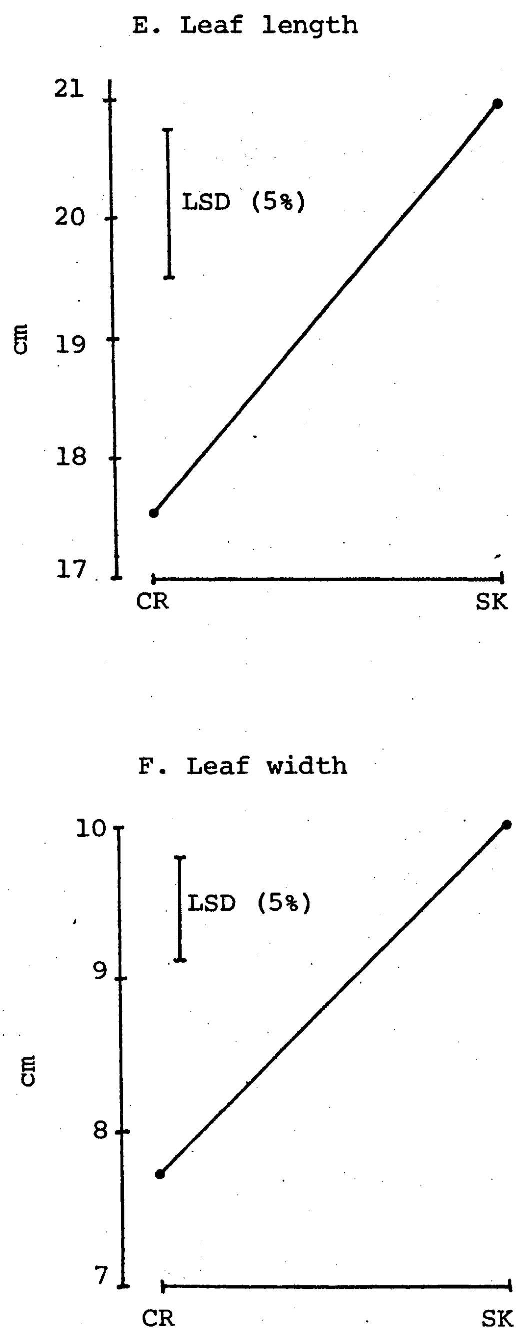


Figure 10.2 - Diagrams showing differences in stem diameter (A), total dry weight (B), relative leaf growth (C), total leaf area (D), leaf length (E) and leaf width (F) between two Thai provenances in experiment 4. CR = Chiengrai; SK = Sukhothai

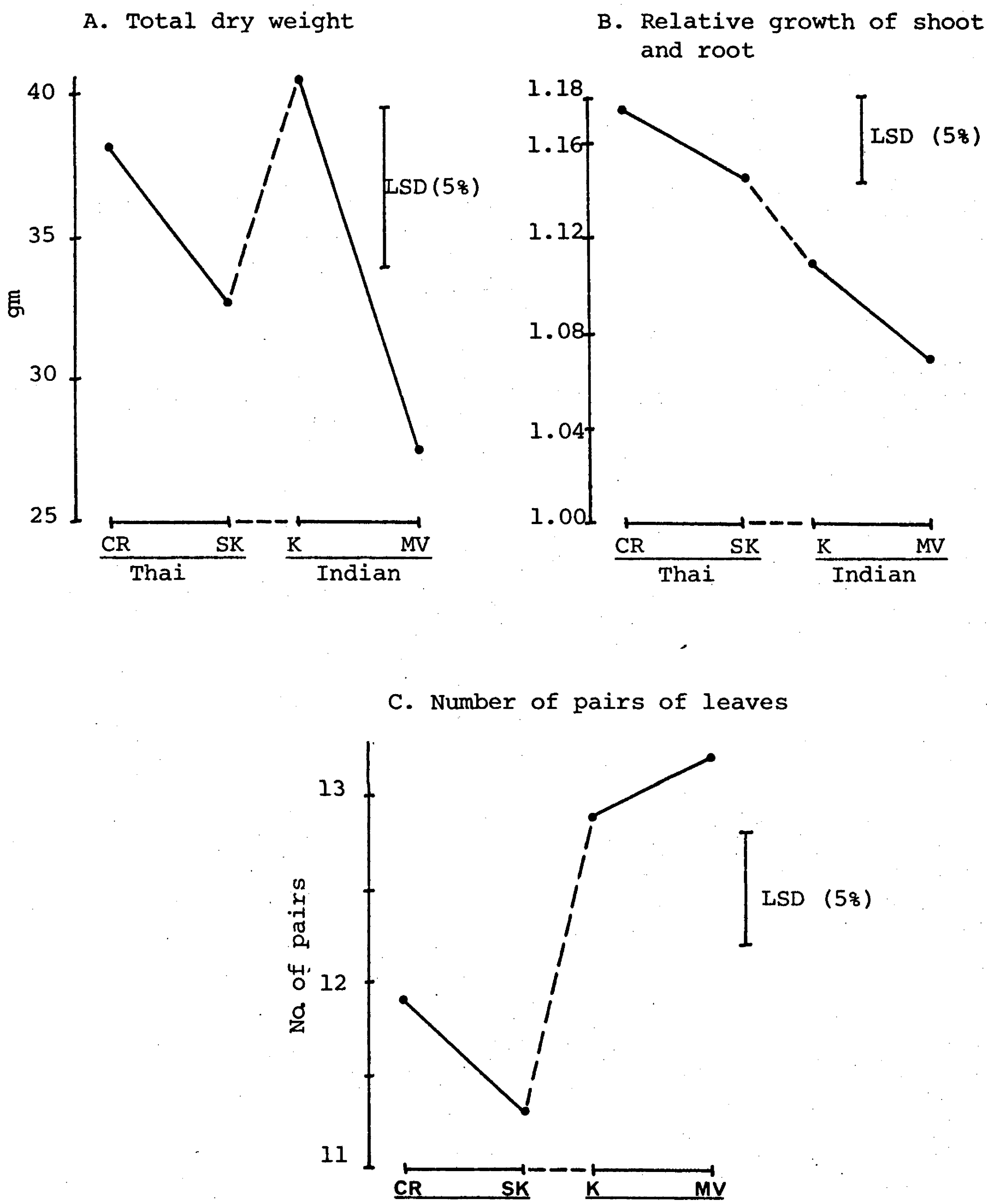


Figure 10.3 - Diagrams showing differences in total dry weight (A), relative growth of shoot and root (B) and number of pairs of leaves (C) between two Thai (CR and SK) and two Indian (K and MV) provenances in experiment 5. Codes for the provenances are given in Table 4.1.

10.6 Summary and Discussion

Provenance variation in teak within Thailand and between Thailand and India was investigated under phytotron controlled environments, using five Thai provenances and two Indian provenances. Of the Thai provenances, two came from the Central and three from the North. Comparisons of provenances were made in terms of overall growth, both directly and using growth analysis parameters, distribution of photosynthate and leaf growth characteristics.

10.6.1 Provenance Variation Within Thailand

There was clear evidence of provenance differences within Thailand. Such differences were found in height growth, diameter growth, dry matter production, leaf area production, leaf dimensions and leaf growth characteristics but not in photosynthate distribution between roots, stem, leaves and between shoot and root (shoot/root ratio). However, there were no clear regional differences (e.g. the Northern vs the Central) from the five Thai provenances studied. Comparisons of seed sources over a wide range within Thailand might result in more definite regional trends. The results obtained indicate the need to include a large number of Thai provenances in the local trials.

In Burma regional differences between northern (Myitkyina) and southern provenance (Toungoo) has been detected (Gyi, 1972).

Two of the seed sources represented early attempts to obtain improved seed:

(a) TIC Seed Source Area No. 1 (SSA) is a seed production area formed by thinning a 30-year old teak plantation to the best 100 stems/ha at the Mae Huad Teak Plantation, Ngao Lampang (North). The source was established by the Teak Improvement Centre, Ngoa Lampang, Thailand in 1972. Seed from this source is used for all genetic research run by the Centre and as a standard provenance in the international trials (see Section 2.4.5.2).

(b) Mae Gah Seed Orchard (SO) is the first clonal teak seed orchard in Thailand, situated at Prayao, Chiengrai (North), established by the TIC in 1966. Sixteen clones from plus trees in local natural stands and plantations are presented in the orchard (Hedegart, 1971). The first seeds were first produced in 1972. The seeds used in this experiment were from the 1973 collection.

Interestingly, seedlings from SSA showed greater height growth, diameter growth and leaf area than did the other provenances (Table 10.2, and 10.5, Figure 10.1A, B and D). These results observed under controlled environments are encouraging for the TIC Seed Source Area.

The results for the materials from seed orchard (SO) are disappointing but this may be due to the orchard not yet being in full flower production and there could have been pollination difficulties and possibly even self-pollination. The seed was noted as being most variable in size and generally very small with slow and poor germination which is a characteristic of seed produced by self pollination in teak (Bryndum and Hedegart, 1969). The Seed Source Area (SSA) results indicate genetic improvement may be obtained through selective ro~~u~~guing rogueing in teak plantations within 30 y of establishment.

Although the Thai provenances were tested under a range of night temperature from 19 to 26^{o}C there was no significant interaction between provenance and night temperature in any study. This suggests genetic differences between Thai provenances are not affected by night temperature. Other environmental factors, e.g. soil type and rainfall might therefore have been more important in the process of natural selection operative within the natural teak stands in Thailand.

Experiment 4 showed significant differences in diameter growth and in leaf area ratio at the short (9.5 h) daylength between two provenances (one from the Central and one from the North). This suggests there could be a possibility of responses of Thai provenances to daylength if grown under short daylengths. It is however, difficult to extrapolate from controlled environment conditions to the field and the daylengths involved are so short and only occur in practice at latitude over 40^{o}. No effects may therefore occur in practice.

Clearly these studies establish that provenance differences exist within Thailand. Therefore, detailed studies of provenance variation in the country are important. The results of variation studies in the field trials (Section 2.4.5.1) need careful examination to determine the most suitable provenances for particular locations.

10.6.2 <u>Variation between Thai and Indian Provenances</u>

There were clear differences between Thai and Indian provenances. Thai provenance had lower net assimilation rate and fewer leaves but greater leaf area ratio and shoot/root ratio. In most parameters studied the Thai provenances were superior to one of the Indian provenances (MV) and comparable to the other one (K) .

Although a provenance x temperature interaction was found in some parameters (e.g. distribution of photosynthate between seedling parts), the provenances varied little over the range of temperature 30/25 to 33/28°C (day/night). No provenances performed well at the lower temperature (24/19°C) but better performances were generally found in the Thai provenances, compared to the Indian, at the high regime (36/31°C). This indicates that the Thai and the Indian provenances compared had a common optimum temperature range. Above this range Thai materials performed better. This suggests that at high temperature the Indian provenances were reducing growth. This may be an adaptation to high temperatures. Similar temperature adaptation was also suggested by Eldridge (1969) for Eucalyptus regnans and Florence and Malajczuk (1970) for Pinus radiata. But in these cases the adaptation was to low temperature.

Provenance differences in a number of characters have been demonstrated between the genetic materials from Burma India, Java and Laos under phytotron environments by Gyi (1972). In his study provenance x temperature interaction also existed and accordingly one Indian provenance (Kerala) exhibited poor growth. This generally agrees with the results obtained from the present study.

The existence of provenance variation in teak is now well established under controlled environment conditions (Chapter 6, 7 and 8, see also chapter 11). The results of the international provenance trials will therefore be most important.

These controlled environment studies have also indicated a provenance x temperature interaction. Again this emphasises the need for detailed international provenance studies to be associated with any major plantation programmes.

CHAPTER 11

Photosynthesis and Respiration in Four Provenances of Teak (Tectona grandis L.f.)

11.1 Introduction

Species which occur over wide geographic range usually show provenance differences in rates of photosynthesis and respiration (e.g. Irving 1967; Duncan and Hesketh 1968; Treharne and Eagles, 1970). Rates of photosynthesis and respiration have been included in provenance studies of several forest tree species (McGregor et al.,1961; Krueger and Ferrell, 1962, 1965; Bourdeau, 1963; Zelawski and Kinelska, 1967; Logan 1971; Neilson et al.,1972). Krueger and Ferrell (1965) reported intraspecific variation in rates of photosynthesis and respiration between two varieties of *Pseudotsuga menziesii*. Seedlings from Vancouver Island (coastal) showed significantly higher rates of both net photosynthesis and dark respiration at certain temperature. Similarly Logan (1971), working with 10 provenances of jack pine (*Pinus banksiana* Lamb) found the tallest p rovenances (at age 7 y) had the highest net photosynthetic rate. In contrast no differences were found between five provenances of Sitka spruce (*Picea sitchensis*) (Neilson et al.,1972) and between *Eucalyptus regnans* seedlings from low and high altitudes (Eldridge, 1969).

Accordingly, an introductory study was carried out to determine whether differences in net photosynthetic and respiration rates exist between provenances of teak.

Such a study would also show the effect of differing temperature regimes on teak photosynthetic and respiration rates. If differences existed at different temperatures these might explain the differences in growth rate reported earlier in this thesis.

11.2 Materials and Methods

Four provenances, two from Thailand (CR and SK) and two from India (K and MV) were used in this study. Full details of the provenances were given in Table 4.1.

Seedlings used were part of a temperature regime experiment (experiment 5). They were established in open glasshouses of 24/19, 30/25, 33/28 and 36/31 ^{o}C on 10/9/75. Growing conditions in these glasshouses and the establishment of the seedlings were detailed in Sections 5.2.1 and 5.3.1 respectively.

The experimental stage began after 46 days. At this stage the seedlings had developed approximately 11 pairs of leaves. Four seedlings of each of the four provenances were moved one at a time from the respective glasshouses to the LB cabinet in which the rates of net photosynthesis and dark respiration were determined. The measurements were made on single intact leaves under the same day temperatures as that prevailing in the seedlings glasshouses. This arrangement of the study is summarized below.

rowing temp(^{o}C) 1 glasshouses	Temperature (^{o}C)compared	Provenances compared	No. of seedlings used (per provenance)
24/19	24	CR, SK, K, MV	4
30/25	30	CR, SK, K, MV	4
33/28	33	CR, SK, K, MV	4
36/31	36	CR, SK, K, MV	4

Fully developed leaves were used, usually leaves 8, 9 or 10 counted from the base.

Photoshynthesis and dark respiration were determined in a closed system (see e.g. Orchard and Heath, 1964; Šesták et al., 1971 (P50-52). The apparatus used is shown diagramatically in Figure 11.1. Air was drawn from the roof of the building into a large mixing drum (200 l) where it was stirred to eliminate short term fluctuations in CO_2 concentration. The air was then split into two lines. One went through a "Flostat" regulator and 'Gapmeter' 12 l flowmeter to the perspex leaf chamber and returned through a similar flowmeter. A coiled copper tube was inserted in the return line, immediately after the leaf chamber. This copper coil was immersed in a water bath maintained at room temperature (25^{o}C). After the 12 l flowmeter, the air in the return line passed through a calcium chloride drying column and through a 2 l flowmeter before going to the IRGA[1/] (sample air). Return air not being passed through the IRGA was vented to the atmosphere.

The other line passed through a calcium chloride drying column, a 2 l flowmeter and finally to the IRGA (reference air). The IRGA was a standard Grubb Parsons SB2. The range switch on the IRGA was arranged so that the reference air could be split to pass through both tubes of IRGA to give a zero for calibration purposes. With the switch in this position the air continued to move through the leaf chamber in a normal manner so that the equilibration of the leaf to the condition in the leaf chamber was not disturbed while the zero was being established.

1/ Infra-red gas analyser

C = Clip
MD = Mixing drum
DC = Drying column

FM = Flowmeter
F = Flostat
WB = Water Bath
LC = Leaf chamber
TW = Thermocouple wire
HR = Honeywell recorder
PT = Plastic tubing
RS = Range switch
IRGA = Infra-red gas analyser
GC = Growth cabinet
S = Seedling
RA = Reference air
SA = Sample air
P = Pump

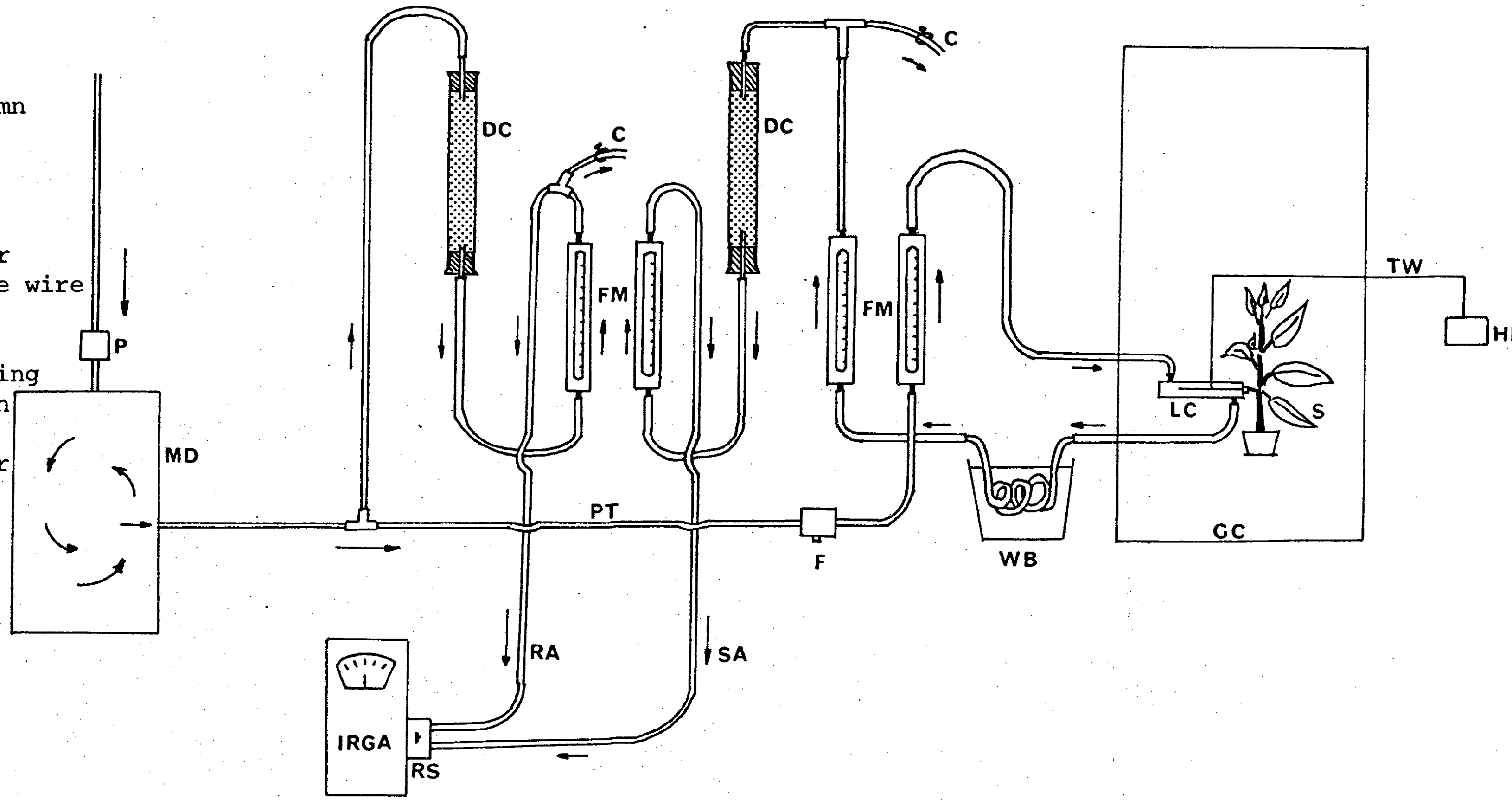


Figure11.1 - Diagram showing the apparatus used to measure net photosynthetic and dark respiration rates.

The growth cabinet was a standard 'LB' type (see Section 3.2.3) with the light supplied by a white fluoresent light bank supplemented by incandescent lamps giving an intensity of 3200 f.c. The temperature inside the leaf chamber was regulated by using the temperature controller of the growth cabinet, and measured with a thermocouple connected to a Honeywell potentiometric recorder.

The volume of the leaf chamber was 1964.70 cu.cm (17.7 x 55.5 x 2.0 cu.cm). The flow rate was regulated by the 'Flostat'. The rate used was 6 l per minute.

The photosynthetic and respiration rates were calculated using the formula modified from Šesták et al.(1971) (P 162).

$$F,\ R_D = \frac{\Delta C \times J \times 44 \times 273 \times P \times 60 \times 10^3 \times 10^2}{10^6 \times 22.414 \times T \times 1013 \times A}$$

$F,\ R_D$ = Photosynthetic or respiration rate (mg dm^{-2} h^{-1})

ΔC = The difference in CO_2 concentration of the air stream before and after the leaf chamber measured at same temperature and pressure (ppm).

J = Air flow rate through the leaf chamber (l/min)

P = Barometric pressure at the time of measurement (assuming equal to 1013 mb)

T = Temperature of flowmeter at the time of measurement (equal to room temperature 25°C)

A = Leaf area (single surface) (sq.cm).

For a given seedling net photosynthesis was determined first and the measurement of dark respiration followed at the same temperature after turning off the light. All measurements were made when the natural light intensity was high between 8.00 am to 4.00 pm. Seedlings were watered before measuring photosynthesis and again at temperatures higher than 24°C before measuring dark respiration.

Following measurement of gas exchange, the enclosed leaf area was determined by 'Automatic Area Meter' (see Section 5.3.3) from a tracing of the enclosed surface of the leaf used.

Data were subjected to standard analysis of variance (Win er, 1971). Treatment differences were determined at 5% level, using least significant difference (Steel and Torrie, 1960).

11.3 Results

There was no significant interaction in the results (Table 11.2) and thus the effects of temperature and provenance could be examined separately.

11.3.1 Effect of Temperature

The highest net photosynthesis occurred at 30°C (10.90 mg $dm^{-2}h^{-1}$) followed in order of magnitude by those at 33 (8.40), 36 (7.79) and at 24°C (5.90) (Table 11.2, Figure 11.2). Differences were significant except the values obtained between 33 and 36°C. Thus optimum temperature for photosynthesis in teak was 30°C.

Dark respiration rate was greater the higher the temperature over the range 24 to 36°C. Mean pooled values for the four provenances ranged from 1.11 mg $dm^{-2}h^{-1}$ at 24°C to 1.73 mg $dm^{-2}h^{-1}$ at 36°C (Table 11.2, Figure 11.2). Differences were significant except the values obtained between 24 and 30°C and between 30 and 33°C.

11.3.2 Provenance Differences

There were very highly significant differences in net photosynthetic rate between the provenances (Table 11.1).

Table 11.1 - Summarized details of the values from the analysis of variance for gas exchange of teak seedlings, showing degrees of freedom, mean square values and significance levels.

Source of variation	Prov (P)	Temp (T)	P X T	Error
Degrees of freedom	3	3	9	48
Net photosynthetic rate (mg $dm^{-2}h^{-1}$)	29.82***	62.28***	1.29	5.39
Dark respiration rate (mg $dm^{-2}h^{-1}$)	0.1323	1.0977***	0.1166	0.1017

*** Significant at 0.1% level

Other values are not significant at 5% level

Table 11.2 - Mean values for net photosynthetic and dark respiration rates (single leaves) of teak seedlings measure at 24, 30, 33 and 36^{o}C.

Parameters	Provenance	Temperature (^{o}C)				Average	LSD (5%)
		24	30	33	36		
et photosynthetic ate (mg dm^{-2} h^{-1})	Thailand						
	CR	5.792	9.859	7.605	6.352	7.402	1.649
	SK	4.073	10.002	6.776	6.592	6.861	(P, T)
	India						
	K	6.384	10.891	9.695	8.587	8.880	3.298
	MV	7.357	12.854	9.535	9.632	9.845	(P X T)
	Av	5.902	10.902	8.403	7.791		
rk respiration te (mg dm^{-2} h^{-1})	Thailand						
	CR	1.112	1.154	1.270	1.546	1.271	0.216
	SK	0.977	1.428	1.484	1.522	1.353	(P, T)
	India						
	K	1.143	1.133	1.420	2.115	1.453	0.374
	MV	1.222	1.383	1.511	1.735	1.463	(P X T)
	Av	1.114	1.275	1.421	1.730		

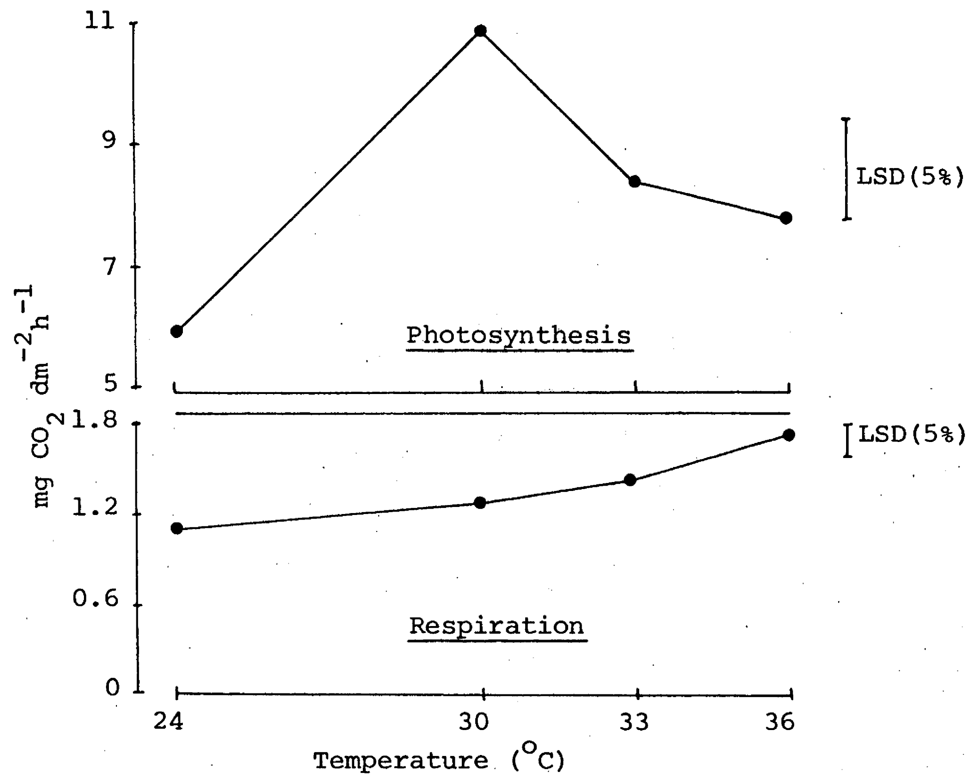


Figure 11.2 - Diagrams showing the effects of temperature on net photosynthesis and dark respiration.

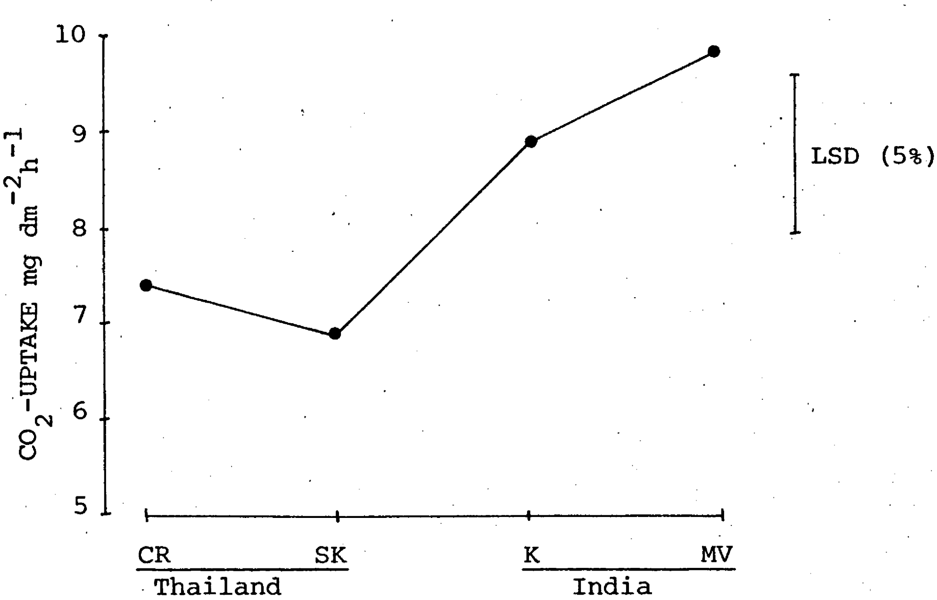


Figure 11.3 - Diagrams showing the differences in net photosynthesis between two Thai (CR and SK) and two Indian (K and MV) provenances. Codes for the provenances were given in Table 5.3.

There appeared to be regional differences between the Thai (CR and SK) and the Indian (K and MV) materials.
The two Thai provenances had similar net photosynthetic rates. The two Indian provenances did also. However, the Thai materials always had a lower rate of net photosynthesis than the Indian materials. Significant differences were found between MV and the Thai provenance (CR and SK) but not between K and CR.

Unlike photosynthetic rate there were no inter-provenance variations in dark respiration. The Indian (K and MV) provenances, however, did show a tendency to be greater than the Thai provenances (CR and SK).

Thus differences in photosynthesis existed between the Thai and the Indian provenances. Although there was no clear evidence of similar variation in dark respiration, there was a trend for greater dark respiration in the Indian materials.

Summary and Discussion

Optimum temperature for net photosynthesis in teak was 30°C. Dark respiration rate was higher the higher temperature over a range of 24 to 36°C. Differences in net photosynthetic rates existed between Thai and Indian provenances with the later having higher rates. Dark respiration rates did not differ between the provenances.

Optimum temperature recorded for teak in this experiment is higher than that recorded for pine and other deciduous temperate trees (see Larcher, 1969, Table 2). In the natural habitats of teak mean monthly temperatures during the growing season generally range from 26 to 33°C (Table 2.2, Figure 2.2 and 2.3). In Northern Thailand the average of mean monthly maximum is 32^{o}C over the period June to October (Appendix 2). Accordingly the temperature for optimum photosynthesis determined under controlled conditions agreed generally with the field situations.

The Indian provenances (K and MV) showed higher photosynthetic efficiency than the Thai provenances (CR andSK). However, the photosynthetic efficiency need not be related to dry matter production.

In experiment 5 dry matter production of the four provenances (K, MV, CR and SK) was compared under the four temperature regimes (24/19, 30/25, 33/28 and 36/31^{o}C). MV was poorest in dry matter production in this experiment (Table 6.6) but has exhibited the highest net photosynthetic rate. Clearly therefore, relative photosynthetic rates of the provenances were not obviously related to dry matter production.

The results of the photosynthetic study also agree with the results of experiment 6 where net assimilation rate of K and MV was higher than that of CR (Table 9.2). Again there was no relationship with dry matter production. Negative or inconclusive correlation between dry matter production and net photosynthesis have been reported by other workers in other species (Ledig and Perry, 1965; Gordon and Gatherum, 1968; Al-Shahine, 1969). In teak, therefore the relationship between net photosynthesis and growth needs further examination.

CHAPTER 12

GENERAL CONCLUSIONS

The objectives of this study were:

(1) To determine the effects of temperature and daylength on growth reponses of teak seedlings.

(2) To determine the extent and pattern of variation in teak within Thailand and between Thailand and India.

To obtain this knowledge, experiments were conducted under controlled environment at CERES phytotron, Canberra, Australia. The following conclusions are drawn from these studies.

(1) Optimum Temperature

The growth of teak seedlings, in terms of height growth, diameter growth, dry matter production, relative stem growth, leaf dimensions and leaf growth is controlled strongly by temperature within the ranges 30 to 33^{o}C for day temperature and 25 to 28^{o}C for night temperature. Above (e.g. 36/31) and below (e.g. 24/19 and 30/13) these ranges the growth declines.

(2) Importance of Leaf Area and Rate of Leaf Elongation

Leaf area is a good indication of growth performance of teak seedlings in respect of dry matter accumulation. Results from leaf growth studies (Chapter 8), growth analysis (Chapter 6 and 9) and gas exchange studies (Chapter 11) indicated dry matter production was closely related to leaf area rather than to net assimilation rate. Also greater relative leaf area production depended on dimensions of individual leaves rather tha on the number of leaves present. In this connection rate of leaf elongation is one of the most important leaf growth parameters affecting the size of individual leaves; the greater the rate of elongation the larger the leaf area. Accordingly, the rate of elongation of particular leaves might be used for predicting performance of teak seedlings either in growth rooms or in the field.

(3) Provenance Differences

The most important practical results of this study are the provenance differences. The provenance differences in Thailand determined suggest the variation in Thai teak may be complex with provenance x site interaction strongly developed. This shows the importance of detailed Thai seed source evaluation Intensive detailed trials for the major teak plantation location will be necessary, particularly as some plantations may have to be outside the species' natural range.

The existence of provenance differences between Thai and Indian materials was clearly demonstrated by this study. (Chapter 10 and 11). According to the results obtained it is probably correct to claim superiority of Thai materials compared to the Indian materials. However, provenances from Burma, Java and Laos were claimed to be superior to Indian provenances (Gyi, 1972) (see also Section 2.5). Thus provenance trials including materials from Burma, Java and Laos particularly should be carried out in Thailand. The detailed trials of materials from these countries will be important as strong provenance x site (temperature) interaction exists between these sources (Gyi, 1972).

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APPENDIX 1

Composition of Nutrient Solution

Nutrient solution, is a modified Hoagland solution, in which the iron is present as a chelate (sequestrene).

Source: Went, F.H. - The experiment control of plant growth. Chronica Botanica Co., 1957, pp.78-79.

The composition is as follows:

$Ca(NO_3)_2.4H_2O$	95g/100 L
$(NH_4)H_2PO_4$	6" "
KNO_3	61" "
$MgSO_4.7H_2O$	49" "
H_3BO_3	0.06 g/100 L
$MnCl_2.4H_2O$	0.04 " "
$ZnSO_4.7H_2O$	0.009" "
$CuSO_4.5H_2O$	0.005" "
$H_2MoO_4.4H_2O$	0.002" "
$Co(NO_3)_2.6H_2O$	0.0025 g/100 L
$FeSO_4.7H_2)$	2.49 g/100 L
EDTA	3.32 "
NaOH	0.50 "

APPENDIX 2

Climatological Data for Lampang Province (Lat $18^{o}15'$N, Long $99^{o}30'$E), 1951-1965

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature (°C)													
Mean	21.7	24.1	27.1	29.8	29.5	28.3	27.9	27.6	27.3	26.3	24.6	22.0	26.4
Mean Max.	30.2	33.1	35.8	37.3	35.1	32.8	32.2	31.7	31.5	31.1	30.9	29.5	32.6
Mean Min.	13.3	15.1	18.4	22.2	23.7	23.9	23.7	23.5	23.0	21.6	18.3	14.5	20.1
Ext. Max.	35.1	37.3	41.0	43.0	41.0	38.0	38.0	37.1	35.8	35.1	35.0	34.2	43.0
Ext. Min.	5.0	6.2	6.2	13.1	19.7	21.3	20.1	20.5	19.0	12.7	9.1	6.1	5.0
Relative Humidity (%)													
Mean	69.3	61.9	55.4	56.1	69.4	76.1	77.0	81.2	84.0	83.4	78.4	74.7	72.2
Mean Min.	96.4	92.8	87.4	84.9	90.1	92.5	92.6	94.9	96.4	97.6	97.5	96.9	93.3
Mean Min.	42.2	35.6	31.4	34.7	51.3	60.6	62.7	66.3	68.8	66.2	55.9	49.6	52.1
Ext. Min.	20.0	15.0	14.0	18.0	21.0	41.0	38.0	45.0	51.0	41.0	36.0	26.0	14.0
Wind (Knots)													
Prevailing wind	SW	SW	SW	SW	SW	SW	SW	SW	S	NE	NE	NE	-
Mean Wind Speed	2.6	3.0	3.4	4.3	3.7	4.0	4.3	3.3	2.6	2.2	1.9	2.2	-
Max. Wind Speed	23SE	48W	70NW	64W	60E	61W	39SW	50SW	44SE	28E	28S	21W	-
Rainfall (mm)													
Mean	4.5	8.4	27.1	48.2	129.0	140.7	120.6	206.7	200.5	116.4	14.4	3.3	1018.4
Mean rainy days	0.9	0.9	3.1	5.2	12.6	16.5	17.5	20.1	18.7	12.5	2.7	1.5	112.2
Greatest in 24 hours	33.1	54.5	47.8	85.1	67.6	103.1	62.6	86.0	75.5	64.3	23.1	13.2	103.1
Day/year	10/58	3/65	7/58	21/56	12/61	6/55	4/60	31/62	8/59	8/54 3/59	5/63	1/60	6/55